#71

REVIEW OF FISHERY STUDIES ON MISSOURI RIVER MAIN STEM RESERVOIRS

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RESEARCH REPORT 71

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REVIEW OF FISHERY STUDIES ON MISSOURI RIVER MAIN STEM RESERVOIRS

Norman G. Benson

RESEARCH REPORT 71

UNITED STATES DEPARTMENT OF THE INTERIOR

Stewart L. Udall, *Secretary*

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FISH AND WILDLIFE SERVICE

Clarence F. Pautzke, *Commissioner*

BUREAU OF SPORT FISHERIES AND WILDLIFE

John S. Gottschalk, *Director*

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ABSTRACT

The six main stem Missouri River reservoirs are described, and information available through 1964 on plankton, water chemistry, fish populations, and water management is discussed. At maximum pool, these reservoirs have a capacity of 76 million acre-feet and a surface area of 1.2 million acres. Each of the upper reservoirs (Fort Peck, Garrison, and Oahe) is larger in capacity and area than the sum of the lower three reservoirs (Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake). Fishes common in this system are bigmouth buffalo, carp, river carpsucker, yellow perch, goldeye, northern pike, sauger, walleye, white crappie, black crappie, and freshwater drum. Available information on growth rates, year-class strength, and relative abundance of common species is described. Limiting factors of the environments are turbidities, wind, and fine soils. Research needs and problems relative to fish production are discussed.

REVIEW OF FISHERY STUDIES ON MISSOURI RIVER MAIN STEM RESERVOIRS

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Bureau of Sport Fisheries and Wildlife

Construction of six main stem reservoirs on the upper Missouri River resulted from consolidation of development plans of the U.S. Army Corps of Engineers and the Bureau of Reclamation for the Missouri River Basin in 1944. The resultant Pick-Sloan Plan considered flood control, navigation, power, and irrigation as the main justifications for these reservoirs. The plan encompassed water development and power projects for the entire Missouri River Basin, and the main stem reservoirs are only a part of a comprehensive program. At full pool, these main stem reservoirs will have a capacity of 76,041,000 acre-feet (9.38×10^{10} cubic meters) and a surface area at maximum pool of 1,261,000 acres (510,326 hectares).

In 1960 it was estimated that the total cost for completion of the main stem Missouri reservoir system would be $1.2 billion (U.S. Army Corps of Engineers, 1960). Percentages of cost allocated to major purposes were as follows: flood control 14.7, power production 62.2, irrigation 13.2, navigation 9.6, and recreation 0.3. The percentage of cost allocated to recreation in the 1960 figure for each main stem reservoir was as follows: Fort Peck 0.24, Garrison 0.24, Oahe 0.31, Lake Shape 0.56, Lake Francis Case 0.30, and Lewis and Clark Lake 2.38 (U.S. Army Corps of Engineers, 1960).

The recreational benefits are expected to increase in importance. General Barney, Chief of the Missouri River Division, U.S. Army Corps of Engineers, stated (1960), "These systems of reservoirs and other works we are building have the primary utilitarian purpose of providing protection, and economic advancement in our Basin, but long after they are completed and serving these purposes, they will best be remembered by the people as family recreation areas." It is significant that fish and wildlife interests were considered in this water development program not only in construction and planning but also in operation of the system.

The main stem system will not be filled and in full operation until about 1970. Water management has been controlled by construction progress and by navigation and flood-control commitments. There is some flexibility in the water management in this system because flood control functions and power production can be shifted among reservoirs. It behooves fishery workers to develop means to exploit fully this flexibility for the production of desirable fishes.

This review assembles the biological in-

formation available on these reservoirs through 1963, to show which fish species thrive and reproduce regularly, the environmental conditions influencing production, changes in abundance of major species by age and water management, ecological changes, and apparent biological trends.

As background material, the climate of the Missouri Basin, topography, general features of each reservoir, and water management system of the main stem reservoirs are described. Much of the material was taken from unpublished reports listed in the references at the end of this report.

The U.S. Army Corps of Engineers, Omaha District, was extremely helpful in providing information on these reservoirs. Studies by fishery workers of Montana, North Dakota, and South Dakota on the Missouri River main stem impoundments have been freely consulted and are greatly appreciated. The studies on physicochemical conditions and phytoplankton by the Kansas City District, U.S. Public Health Service, under the direct supervision of Dr. Joe Neel, have been of inestimable value.

CLIMATE AND RUNOFF

Hart (1957) paints a rather dreary picture of the climate of the upper Missouri River Basin because of its variability by year, season, and over extended periods. Tree ring analyses back to the 15th century have shown the same irregular variations as are still present.

The greatest annual extremes are found in the northern part of the basin (western North Dakota), where the average annual summer maximum temperature is 130° F. higher than the average winter low. The climate in the main stem system varies from semiarid in the north to semihumid in the south.

The average annual rainfall varies from 15 inches in the Fort Peck area to 25 inches at Lewis and Clark Lake (table 1). Mean air temperatures on August 1 range from 70° F. in the Fort Peck area to 75° F. at Lewis and Clark Lake and from 10° to 19° F. on February 1. Ice cover on these reservoirs ranged from 85 to 123 days during the period from 1958 to 1964.

Winter winds are predominantly from the northwest, and summer winds from the southeast, but great variations occur. Velocities are usually highest in spring, when they average 10 to 14 miles per hour. Winds in excess of 50 miles per hour are not uncommon. They are lowest during late summer months, when they average 6 to 9 miles per hour. Blizzards are common in the upper basin during winter.

Annual discharge of the Missouri River at Sioux City, Iowa, (60 miles below Lewis and Clark Lake) from 1898 to 1958 averaged 24 million acre-feet but ranged from 11 to 37 million acre-feet. Greater proportionate variations in discharge have been recorded in other sections of the river and

TABLE 1.—*Average annual rainfall, air temperature on August 1 and February 1, days of ice cover, and closing and opening dates of ice cover on Missouri River main stem reservoirs, 1958–64*

[Rainfall and air temperature data from U.S. Army Corps of Engineers (1960)]

Reservoir	Average annual rainfall (inches)	Mean air temperature (° F.)		Average days of ice cover, 1958–64	Median dates of ice cover, 1958–64	
		Aug. 1	Feb. 1		Closing	Opening
Fort Peck	15	70	10	[1] 85	Jan. 1[1]	Apr. 4[1]
Garrison	15	70	10	[2] 123	Dec. 21[2]	Apr. 22[2]
Oahe	17	72	15	103	Dec. 15	Apr. 6
Lake Sharpe	17	73	18	----------	--------	--------
Lake Francis Case	20	73	19	95	Jan. 1	Apr. 3
Lewis and Clark Lake	25	75	19	118	Nov. 29	Apr. 5

[1] 1960–64. [2] 1959–64.

in tributaries. The main stem system has the capacity (76 million acre-feet) to store three times the average annual flow at Sioux City.

TOPOGRAPHY AND LAND USE

The Rocky Mountains form the western border of the basin, but the entire basin where main stem reservoirs were constructed is plains country with elevations ranging from 2,250 feet above mean sea level at the upper end of Fort Peck Reservoir to 1,160 feet at Lewis and Clark Lake (fig. 1). This high plains country is a large coalesced alluvial fan, which was formed from streams draining eastward from the Rocky Mountains (Emerson, 1920). The present location of the Missouri River marks the southern edge of Pleistocene glaciation (Longwell, Knopf, and Flint, 1947). Thus, till and other glacial deposits overlay the north and east shores of the river. The drainage basin south and west of the river is overlain with extensive sedimentary deposits which are vividly exposed in the Badlands of North and South Dakota. Except for a few trees in the river valleys and protected areas, the area was originally short-grass plains country. Presently the upper part of the basin in Montana and North Dakota is used principally for wheat, flax, or grazing, except where irrigation has been developed. In South Dakota the area west of the river is used principally for grazing and wheat farming. The area east of the Missouri River is used for fairly intensive cultivation of row crops. Except for the headwater area, the soils in the entire basin are fine and erodable and the unimpounded rivers are laden with silt. The principal surface sediments are shales or consolidated clay particles and chalk. The high turbidities in the basin are caused by flattened clay particles which, though light in weight, effectively shield out light.

OPERATION OF RESERVOIRS

The functions of each main stem reservoir were established by Congress. To accomplish these functions the U.S. Army Corps of Engineers (1960) established four operational zones in each reservoir with regard to capacity and elevation:

1. Exclusive flood control reserve.—This top zone is for emergency only, for detention of extreme or unpredictable floods. After this zone is filled, it is evacuated as rapidly as possible.

2. Annual flood control and multiple-use capacity.—This upper level is designed for normal floods and release of flood flows for "multiple use" benefits. Multiple use includes power production, water supply and sanitation, navigation, irrigation, recreation, and fish and wildlife. This zone is normally evacuated by March 1 each year to provide storage capacity for spring floods. Flood control predominates over other purposes.

3. Carryover multiple-use capacity.—This intermediate zone is a reserve for multiple-use purposes. The storage is accumulated over wet periods and is utilized during dry periods. It has no flood control function.

4. Inactive capacity.—This bottom inactive capacity is reserved for power head, sediment storage, irrigation, and minimum level for recreation. After initial fill, reservoir levels will be drawn into this zone only in emergencies.

The Missouri River Reservoir Control Center in Omaha, Nebr., establishes the water regulation program for each reservoir on the main stem and in tributaries. The amount of water stored, climate, rainfall, tributary stream flow, and multiple-use requirements, are considered in formulating a program for the entire system by April of each year.

The main stem reservoirs differ greatly in size, depth, and water management requirements (table 2). Each of the upper

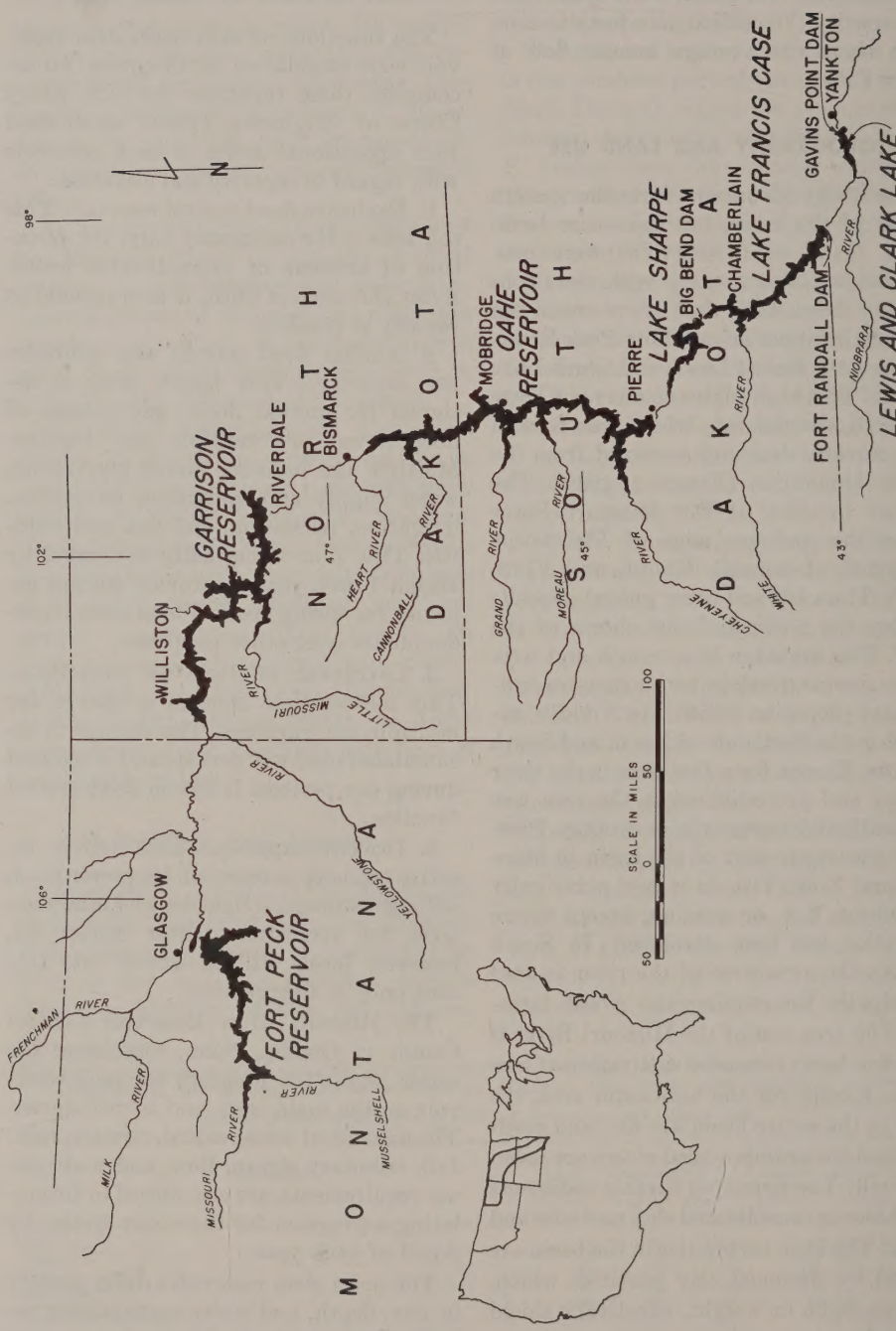

FIGURE 1.—Main stem Missouri River reservoirs.

three reservoirs, Fort Peck, Garrison, and Oahe, is larger in surface area and volume than the sum of the lower three reservoirs, Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake. These upper reservoirs will be used for long-term water storage, and their annual water management will not be as uniform as in the lower three reservoirs. The water levels of the upper reservoirs will be controlled by climatic conditions and available runoff. The lower reservoirs will be managed quite uniformly because their storage capacities are relatively small, and they must depend upon water stored in the upper reservoirs for operation during dry periods. It should be noted that 70 percent of the capacity of this system is reserved for multiple-use purposes (table 2).

GENERAL DESCRIPTION OF RESERVOIRS

The main stem system impounds 897 miles of river, at full pool, from Gavins Point Dam in South Dakota to the headwaters of Fort Peck Dam in Montana (fig. 1). Only 317 miles of free-flowing river exist within the impounded section of the river. All reservoirs are long and narrow, with Oahe reaching a maximum length of 250 miles at full pool (table 3). Fort Peck, with a maximum depth of 250 feet, is the deepest. Trees and brush were not cleared from the reservoir bottom except in a few areas where heavy recreational use was expected. The descriptions below include morphometry, water management, and use.

Fort Peck

This reservoir was closed in 1938, before the development of the Pick-Sloan Plan, but its management was incorporated into the main stem system in 1944. It is 190 miles long and has a 1,600-mile shoreline and an average depth of 79.2 feet at maximum pool (table 3). Water levels up to 1953 showed a fairly constant annual fluctuation of 15 to 20 feet with spring rise to a maximum in July, and receding water levels in late summer and fall (fig. 2). As additional reservoirs were impounded, the water was lowered to fill these and to fulfill power and navigation requirements. Future water level management will show long-term fluctuations characteristic of the period 1955 to 1963 (fig. 2) in contrast to the type of water-level program illustrated for 1952 and 1953.

TABLE 2.—*Volume, surface area, depth in each operational zone, and total capacity of Missouri River main stem reservoirs*

Item	Fort Peck	Garrison	Oahe	Sharpe	Francis Case	Lewis and Clark	Total
Exclusive flood control:							
Volume, 1,000 acre-feet	1,000	1,600	1,100	175	900	64	4,839
Surface area, 1,000 acres	245	428	376	61	118	33	1,261
Depth of zone, feet	4	4	3	3	10	2	26
Annual flood control and multiple use:							
Volume, 1,000 acre-feet	2,700	4,400	3,200	0	1,400	103	11,803
Surface area, 1,000 acres	233	360	358	0	104	31.3	1,086.3
Depth of zone, feet	12	12.5	9.5	0	15	3.5	52.5
Carry-over multiple use:							
Volume, 1,000 acre-feet	11,200	13,600	13,800	260	2,400	218	41,478
Surface area, 1,000 acres	212	329	324	56.5	82	27.5	1,031
Depth of zone, feet	26	37.5	67.5	5	40	9.5	185.5
Inactive capacity:							
Volume, 1,000 acre-feet	4,500	4,900	5,500	1,465	1,400	156	17,921
Surface area, 1,000 acres	93	133	119	49	42.5	18	454.5
Depth of zone, feet	130	102	125	70	80	35	542
Total pool:							
Volume, 1,000 acre-feet	19,400	24,500	23,600	1,900	6,100	541	76,041
Surface area, 1,000 acres	245	428	376	61	118	33	1,261
Maximum depth, feet	220	191	205	78	145	58	897
Height of power outlets above bottom, feet	64	0	125	0	0	0	----------

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The annual water exchange rate was 2.3 in 1962 and 3.4 in 1963 (table 4). The exchange rate is highest during summer and fall. Present use for sport fishing is light because of its isolation. Commercial fishing is insignificant (table 5).

Garrison Reservoir

Garrison Reservoir, with dam closure in 1953 and initial hydroelectric operation in 1956, is the largest reservoir of the main stem system in capacity and surface area (table 2). The local drainage area is relatively flat and semiarid. The slope above inactive pool is the least in the system. Water management to date shows no consistent annual pattern, and it has never reached elevation within the annual flood control zone (fig. 2). The annual water exchange rate was 1.26 in 1962 and 1.51 in 1963; this rate will decrease as the water level rises. Average depth from top of inactive capacity to maximum pool changes only from 55.8 to 57.1, which reflects the extremely flat terrain. Sport fishing and commercial fishing are light in relation to the size of this reservoir (table 5).

Oahe Reservoir

Only slightly smaller than Garrison in capacity and surface area, Oahe Reservoir has an unusually long shoreline because the Cannonball, Grand, Moreau and Cheyenne Rivers enter it on the west shore (fig. 1).

TABLE 3.—*Maximum pool length, average depth at top of each operational zone, shoreline length at maximum pool, shoreline development, average width, and slopes of Missouri River main stem reservoirs*

[Lengths in miles and depths in feet. Shoreline development is the ratio of shoreline length of the reservoir to circumference of a circle equal in area to the reservoir]

Item	Fort Peck	Garrison	Oahe	Sharpe	Francis Case	Lewis and Clark
Maximum pool length	190	200	250	80	140	[1] 21
Average depth at top of zone:						
Exclusive flood control	79.2	57.1	62.8	31.1	51.7	16.3
Annual flood control and multiple use	79.0	55.8	62.8	----------	50.0	15.2
Carryover multiple use	74.1	56.2	59.6	30.5	46.3	13.6
Inactive	48.4	36.8	46.2	29.9	32.9	8.7
Shoreline length, maximum pool	1,600	1,500	2,350	175	575	50
Shoreline development at top of—						
Annual flood-control pool	23.1	16.3	27.4	5.1	11.9	2.1
Carryover pool	23.5	16.7	28.2	6.0	13.5	2.1
Average width, maximum pool	2.0	3.3	2.4	1.2	1.3	2.1
Average slope of impounded section of river in feet per mile	1.16	.96	.82	.97	1.04	1.35
Average slope in feet per mile from top of inactive to maximum pool	.59	.27	.31	.67	.86	1.00

[1] Figured at 1,208 feet above mean sea level, where reservoir is normally operated.

TABLE 4.—*Water exchange rates in Missouri River main stem reservoirs, by months, 1962 and 1963*

[Computed by dividing storage at end of month by monthly outflow]

Month	Fort Peck		Garrison		Oahe		Francis Case		Lewis and Clark	
	1962	1963	1962	1963	1962	1963	1962	1963	1962	1963
January	11.9	21.6	6.6	10.1	8.9	11.5	8.7	7.0	0.7	0.9
February	12.2	20.1	6.8	11.1	20.6	14.4	13.6	25.7	.8	1.4
March	12.9	24.6	6.5	10.4	33.4	17.7	14.3	9.4	.8	.6
April	18.1	51.8	7.0	13.8	15.7	10.5	11.4	2.6	.6	.3
May	38.2	55.0	6.9	16.2	7.1	5.8	4.9	--------	.4	.3
June	25.1	50.6	9.3	17.1	37.1	6.5	7.5	3.0	.4	.3
July	31.8	55.4	16.2	16.5	31.5	6.0	4.5	3.0	.3	.2
August	32.0	62.3	23.7	31.6	14.9	6.0	3.4	2.3	.3	.2
September	42.5	47.8	28.9	29.7	22.2	8.5	2.3	2.3	.3	.2
October	53.5	30.5	17.4	24.5	12.4	7.8	1.8	1.6	.3	.3
November	32.1	51.8	27.9	16.4	15.2	9.3	1.7	1.7	.3	.3
December	21.7	24.9	14.8	10.6	10.7	5.7	5.0	4.7	.8	.8
Mean	27.7	41.4	15.2	18.2	19.1	9.1	6.5	5.7	.5	.5
Annual	2.3	3.4	1.3	1.5	1.6	.8	.5	.5	.04	.04

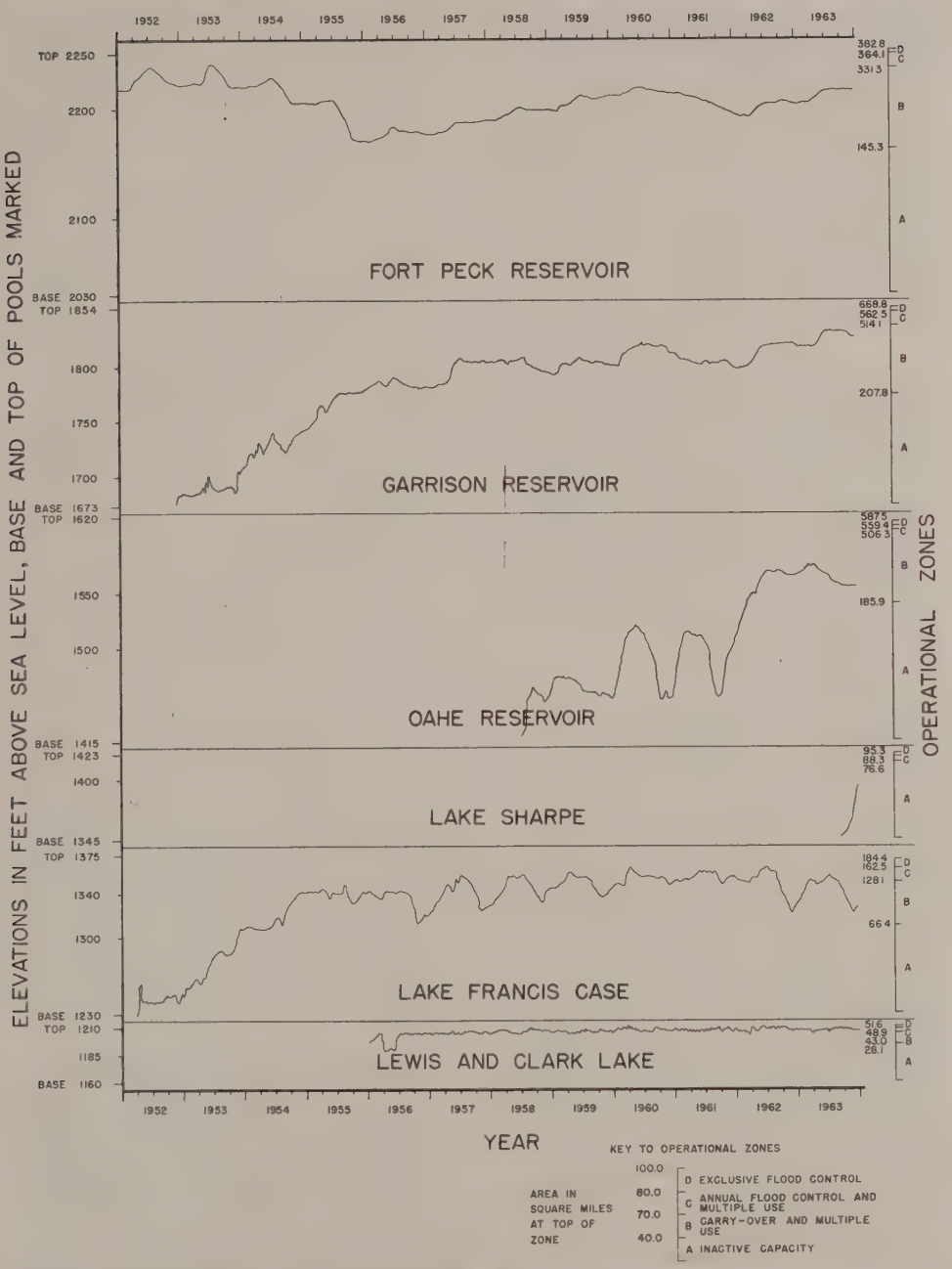

FIGURE 2.—Water levels of Missouri River stem reservoirs, 1952 to 1963, with operational zones delineated.

TABLE 5.—*Estimated number of visitors, sport fish catch, and commercial fish catch in Missouri River main stem reservoirs and tail water below the dams in 1961*

[From U.S. Army Corps of Engineers (1962)]

Reservoir	Thousands of visitors	Thousands of pounds of sport fish caught	Thousands of pounds of commercial fish caught
Fort Peck	202.1	30	17.3
Garrison	416.8	550	157.6
Oahe	220.5	195	0
Lake Francis Case	479.5	115	276.5
Lewis and Clark Lake	1,880.5	416	0
Total	3,199.4	1,306	451.4

The dam was closed in 1958. At top pool, it will have an average depth of about 60 feet, a maximum depth of 205 feet. Still in the filling stage, water levels to date are not indicative of the operational plan. The outlet of the Oahe Reservoir is 125 feet above base level, which will influence current patterns and thermal stratification. A commercial fishery was initiated in 1964. Sport fishing pressure was low in the reservoir up to 1964.

Lake Sharpe

This reservoir has a flood control storage capacity of 175,000 acre-feet, but its main purpose is power production. It is 80 miles long, and its average width is 1.2 miles. The reservoir (named Lake Sharpe by Congress) was formed by the closure of Big Bend Dam in 1963. Inflow comes from 125 feet above the bottom (altitude 1,540 feet) in Oahe Reservoir. Water level fluctuations, although small (2 to 4 feet), will occur daily owing to diurnal variations in power demand. With an average depth of 50 feet, maximum depth of 145 feet, and a high water exchange rate, the reservoir is not expected to stratify significantly.

Lake Francis Case

Fort Randall dam was closed in July 1952, but a significant rise in water level did not begin until January 1953 (fig. 2). The reservoir was named Lake Francis Case by Congress in 1962. At maximum pool, this reservoir is 140 miles long, has an average depth of 51.7 feet, and averages 1.3 miles in width (table 3). Future water level management can be expected to follow the 1957 to 1961 pattern with variations to reflect multiple-use demands and water supply (fig. 2).

Lake Francis Case has many short bays but few large protected areas free from wind action. Large areas of trees and brush are still present. In the 10 years since dam closure a rubble shoreline has developed in many areas because fine silt particles have been removed from the shoreline and deposited in deep areas, exposing the underlying rubble. Its recreational use is expected to increase because of its accessibility. A commercial fishery has developed (table 5).

Lewis and Clark Lake

Lewis and Clark Lake is the smallest reservoir of the main stem system in terms of both capacity and surface area (table 2). It regulates flow from Fort Randall Dam and has an exchange rate of 9 days during summer. With an average depth of 16 feet and a maximum depth of 58 feet, it is influenced to a greater degree by local changes in wind and air temperature than the larger reservoirs. Because of its small capacity, Lewis and Clark Lake has a long perior of ice cover, even though it is the southermost of the reservoirs (table 1). This reservoir has the highest recreational use in the system because of its location and relatively constant water level.

RESERVOIR ENVIRONMENT

Because they contain features of both rivers and lakes, environmental conditions in reservoirs are dynamic and difficult to describe. Stepanek (1960) stated that reservoirs can never be described with the relatively simple terminology commonly used for glacial lakes. Rawson (1958) summarized significant morphometric, chemical, physical, and biological measurements

that have been made on natural lakes that could be applied to reservoirs. Significant differences were time of flushing and current patterns. He suggested that reservoirs show greater individual variation than natural lakes simply because many of the biological characteristics are not understood.

Since one of the principal purposes of the Missouri River impoundment system is flood control, the system will probably never be completely filled. With average rainfall, the system will be operated between 80 and 95 percent of capacity. Except for reservoir morphometry, all limnological features presented represent only trends that have been measured during the early years of impoundment. Subjects discussed include reservoir morphometry, bottom types, common chemical constituents of the water, plankton populations, and bottom fauna. Vascular aquatic plants are rare in these reservoirs and have not been studied.

MORPHOMETRY

The morphometry of a reservoir has many implications that must be considered in management for fish production. It may be of greater importance in reservoirs than in natural lakes because the shape of the water mass commonly changes at different water levels. Morphometry is a function of the height of the dam and the topography of the impounded area. In the upper Missouri Valley, the original flood plain wherein the river meandered is relatively flat and is contained by bluffs. Above the flood plain the topography undulates to a great degree owing to erosion by intermittent and permanent streams.

The fact that the Missouri River is the southern edge of Pleistocene glaciation has influenced the form of several reservoirs. The nonglaciated terrain west and south of the river has been subject to long-term erosion and is hillier than the relatively flat glaciated land east and north of the river. Thus, the west shores of several reservoirs (Oahe, for example) have many more protected areas than the east shores because of the inundation of stream mouths and the associated rolling terrain. Many sections of the east shores are hilly because of moraine deposits and relatively recent erosion. Shoreline development, average depth, and slope of shoreline—morphometric factors that influence biological production—will be discussed.

Shoreline development

A high shoreline development denotes more protected areas which may be particularly important in this windy region with its fine soils. Although littoral production of bottom animals is reduced in reservoirs by water level fluctuation, plankton production is normally greater in shallow areas than in deep areas (Verduin, 1956). In addition, unpublished studies on Lewis and Clark Lake have demonstrated that burrowing mayflies are abundant only in exposed areas of the reservoir below 10 feet in depth, or below the direct effects of wind action; abundance was high also in a few protected areas with less depth. Unpublished studies on the periphyton of submerged trees show maximum abundance at the 10-foot depth in exposed areas. Because these reservoirs are long and narrow, they have higher shoreline developments than most natural lakes of comparable area as quoted by Hutchinson (1957). Larkin (1964) pointed out the fallacies of comparing long narrow bodies of water with broadly shaped lakes and suggested that many of the accepted biological advantages of a large shoreline would not apply in long narrow bodies of water.

Lewis and Clark Lake, which has few protected areas and just covers the flood plain, has a shoreline development of 2.1 (table 3). This is moderately high for a natural lake but the minimum for reservoirs in this system. Lake Sharpe has a

few protected coves, but it includes an old river meander which never became cut off; it has a shoreline development of 6.9. Lake Francis Case rises above the flood plain but not high enough to inundate the deeply sculptured topography at slightly higher elevation. Shoreline development reaches 13.5 at the top of the carryover pool, which is moderate for this chain. Garrison Reservoir inundates a flat area and has a shoreline development of 16.3 at the top of the annual flood control pool. Both Fort Peck and Oahe inundate heavily rolling terrain. Shoreline development at Oahe is 27.4, and at Fort Peck is 23.1. In this system, shoreline development of less than 10 includes those reservoirs that are confined almost entirely to the flood plain.

Average depth

Average depth reflects the slope of the shoreline at different water levels. Larkin (1964) reviewed many studies of natural lakes and demonstrated how average depth was inversely related to fish production. The large area of littoral zone in shallow natural lakes, with its associated high plankton and bottom fauna production, was suggested as one of the principal reasons for the relation of fish production to average depth. Ryder (1965) used average depth plus total dissolved solids to predict fish production in natural lakes.

The relation between water level and mean depth for the entire system approximates a 1-foot increase in mean depth for every 3.3-foot rise in water level, or about a 33-percent slope (fig. 3). This relation does not apply to all pool levels of any reservoir. Garrison Reservoir has a negative slope in the 150- to 160-foot depth range, and Oahe has only a 7-percent slope in the 110- to 140-foot range. The small slope in Oahe is located near the inactive pool water level while the Garrison condition is located within the range of expected water level operation (fig. 3). It is probable that the area of littoral zone will be highest and production greatest where the water level-mean depth slope is least positive or even negative. This relation will not influence Lewis and Clark Lake, Lake Sharpe, or Lake Francis Case because none approaches a water level where the slope decreases.

The average bottom slope of these impoundments from inactive to maximum pool is greatest in Lewis and Clark Lake (1.00) and decreases directly with the surface area of the other reservoirs (table 3). This same relation is reflected in the average depth-water level slope (fig. 3). As each reservoir in this system rises in water level, the average slope of the shoreline decreases because the terrain at higher elevation tends to flatten out.

BOTTOM TYPE

Most of the reservoir bottoms are a mixture of fine sediments and sand. Before construction of the dams, the sediment load of the Missouri River consisted of about 70 percent fine sediment and 30 percent sand, and these sediments make up a large part of the reservoir bottoms. Some parts of each reservoir have outcrops of chalkstone (loosely consolidated limestone) and shale. Shields (1958b) noted that the chalk outcrops developed into a fairly compact bottom type after wave action removed the finer materials. Lake Sharpe is the only reservoir where glacial till is exposed in quantity, although there are small outcrops below Fort Randall Dam and in the other reservoirs. Recent unpublished studies on Lewis and Clark Lake, after 8 years of impoundment, have shown that old fields developed suitable bottom deposits for good bottom fauna production, but the value of most of the reservoir bottoms to biological production at this time is unknown.

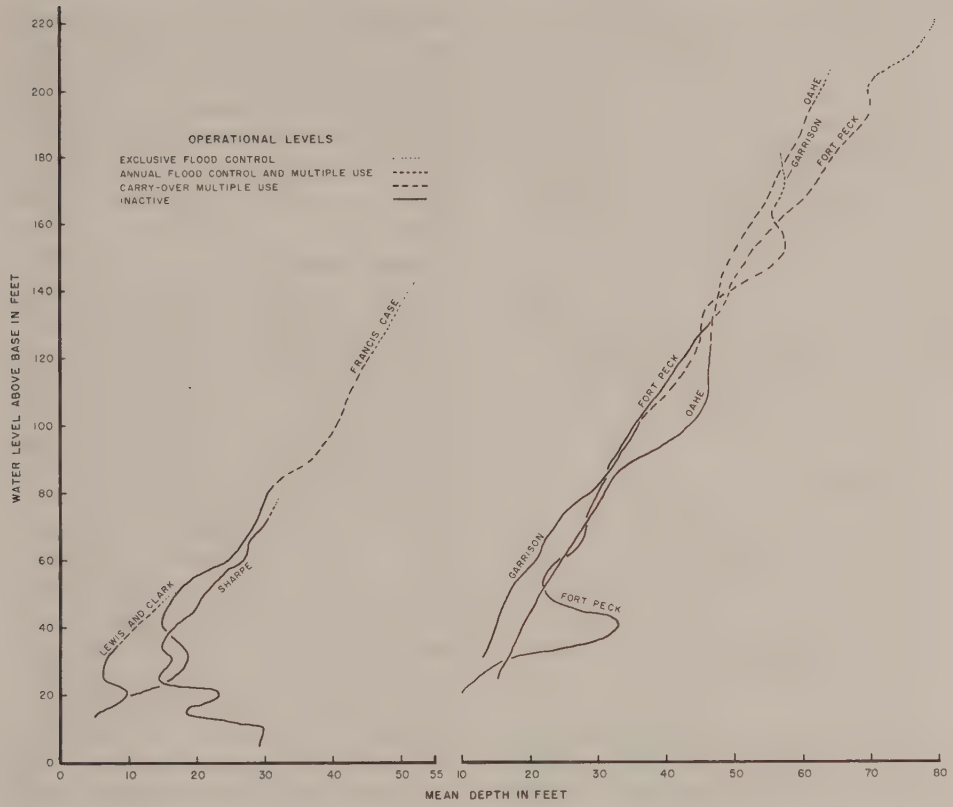

FIGURE 3.—Water levels of Missouri River main stem reservoirs as related to average depth, with operational zones delineated.

WATER TEMPERATURE

The thermal patterns of Fort Peck, Garrison, and Lake Francis Case have been measured by the U.S. Army Corps of Engineers, and it is possible to describe both seasonal and annual variations.[1] With the addition of spot measurements from Lewis and Clark Lake, and Oahe, it is possible to anticipate the general temperature structure of the entire system.

[1] Data on water temperature, total dissolved solids, suspended solids, and water density were collected by the U.S. Army Corps of Engineers, Omaha District. The isocontours of the above parameters were constructed from stations at 5-mile intervals from the dam to the uppermost section of each reservoir sampled. Measurements by depth were taken at 10-foot intervals from the surface to the bottom.

Fort Peck

Extensive data collected in the 1948–62 period showed that, after the ice breakup, the warming process begins in the upper end of Fort Peck Reservoir and advances downstream and to greater depths during the summer (fig. 4). Although the outlet is 64 feet above base level, it drains the reservoir close enough to the bottom to reflect bottom temperatures. By late May 1951 the 45° F. isotherm had advanced to the dam and the 55° F. isotherm was in the upper end of the reservoir. By late June the 70° F. isotherm was entering the upper reservoir and the 45° F. isotherm had almost disappeared from the water mass.

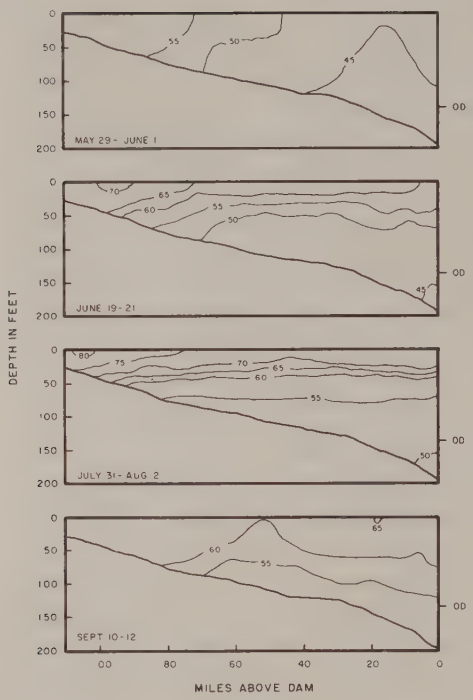

FIGURE 4.—Distribution of 5° F. isotherms in Fort Peck Reservoir during 4 periods of 1951.

By late July the entire surface was above 70° and an 80° F. isotherm had started to develop in the upper end. Except for a small section below 50 feet in depth near the dam, the water temperature was between 50° and 60°. A rather distinct stratification developed at the 30- to 50-foot range and extended the entire length of the reservoir. By mid-September the surface water had reached the low sixty's and all of the water below 50° F. had been drained from the reservoir.

A typical annual pattern from a station 5 miles above the dam illustrates how the 55° F. isotherm leaves the water mass for a short period in October (fig. 5). It should be noted that the fall cooling process is more abrupt than the warming process and progresses rapidly after the water mass becomes homothermous. Differences among years were evident from measurements made in late July to mid-August in 1948, 1950–52, and 1961 (fig. 6). In all years stratification was present in the top 50 feet of water. Anderson and Pritchard (1951) recorded a similar pattern of temperature development in Lake Mead, a 146,500-acre reservoir on the Colorado River.

Garrison Reservoir

As in Fort Peck, the warming process begins in the upper end of the reservoir and progresses downstream (fig. 7). The 45°, 50°, and 55° F. isotherms move downstream and to greater depths as the season progresses. In 1958, 1959, and 1960, temperatures were measured 2.5 miles above the dam (fig. 8) In all years the 55° F. isotherm had disappeared by September. Water above 70° F. was present only in late July and August, and temperatures within the 60° to 70° F. range occupied most of the upper 50 feet of water. By October the water became homothermous, and temperatures decreased homothermally until ice formed in late November or December. Stratification was not as distinct in Garrison as in Fort Peck, although in 1958 and 1960 there was stratification at 50 to 70 feet during August.

Oahe Reservoir

Oahe is similar to Garrison in size, but the power outlet of Oahe is 125 feet above the base of the dam rather than at base level. This fact will prevent the draining of deep cold water and should result in more stable stratification. Past measurements of the thermal patterns do not show this trend because the water drained through outlet tunnels rather than through the turbines, and the reservoir had not reached normal operating levels. Fogel's (1963b) temperature data for 1962 suggest that Oahe will stratify more distinctly than Garrison and this trend should intensify as the water level rises. Surface temperatures averaged about 6° F. higher

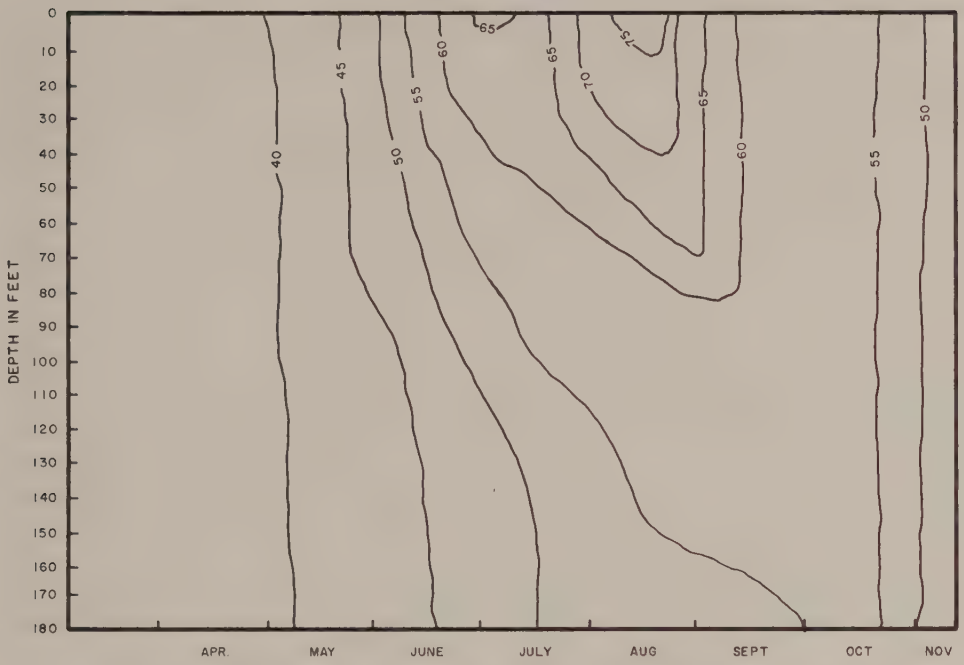

FIGURE 9.—Distribution of 5° F. isotherms in Lake Francis Case, 1955, 1956, and 1962.

than at Garrison and about 4° F. lower than at Lake Francis Case (table 6).

Lake Sharpe

Data are not available from this reservoir because it has not reached operating levels. It is reasonable to expect that thermal conditions will develop in Lake Sharpe that are not present elsewhere in the system. First, the upper end of Lake Sharpe will reach the base of Oahe Dam and water level fluctuations in Lake Sharpe will be slight. Second, the outlet of Oahe is 125 feet above base level and from 20 to 40 feet below the surface, depending on water level. When Oahe is operating within the upper levels of the carryover pool, the temperature of the incoming water of Lake Sharpe is expected to be from 50° to 60° F. during the summer months. This water may form a density current in Lake Sharpe that will reach to the dam. Surface temperatures in Lake Sharpe should be in the 70° to 80° F. range if this density current develops.

Lake Francis Case

This reservoir is considerably warmer than Fort Peck or Garrison, and almost the entire water mass rises above 70° (fig. 9). Surface temperatures during late July and early August are usually above 75° F., and temperatures above 80° F. have been frequently recorded. The warming cycle begins in the upper end and progresses downstream. As in Fort Peck and Garrison, the colder water is drained out of the reservoir through the penstocks.

Lewis and Clark Lake

In this shallow reservoir, rapid exchange of water prevents any development of stratification except for occasional periods on calm days. Temperature differences of 1° to 5° F. from surface to bottom are common, but a distinct thermocline never

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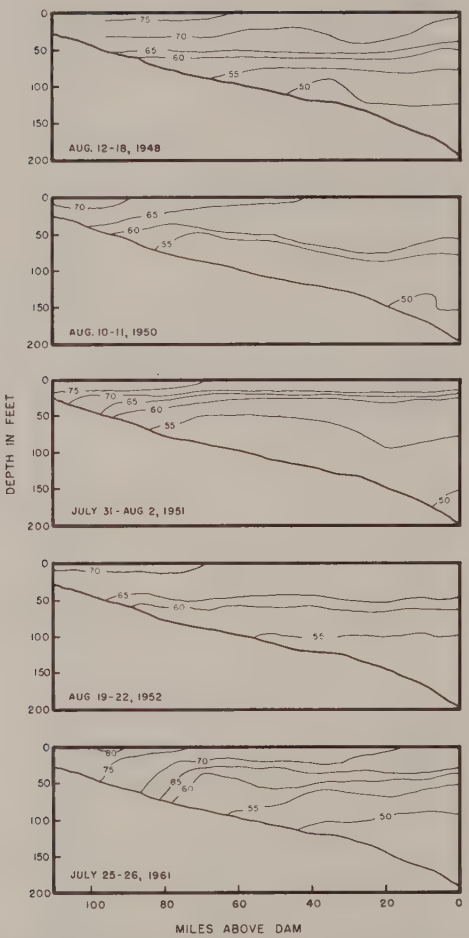

FIGURE 6.—Distribution of 5° F. isotherms in Fort Peck Reservoir in summers of 1948, 1950, 1951, 1952, and 1961.

develops. Water temperatures are in the 70° to 80° F. range during the summer.

Entire system

All of these reservoirs develop ice cover, but summer surface water temperatures are about 10° colder in Fort Peck and Garrison than in Lewis and Clark Lake. Fort Peck has the most distinct stratification. Garrison develops temporary stratification in many areas, but heavy winds

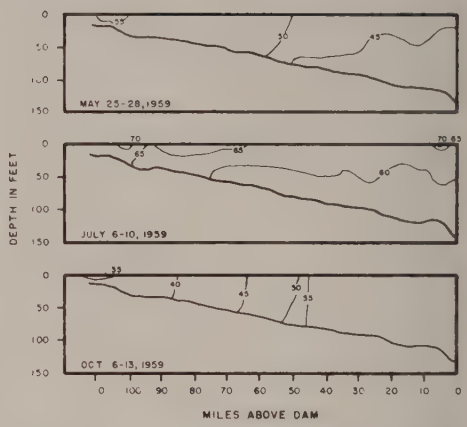

FIGURE 7.—Distribution of 5° F. isotherms in Garrison Reservoir during three periods of 1959.

TABLE 6.—*Mean surface water temperatures during June, July, and August on Missouri River main stem reservoirs.*

[In Fahrenheit degrees]

Reservoir and year	Mean surface water temperature in—		
	June	July	August
Fort Peck:			
1949	62	69	72
1950	----	----	67
1951	64	75	----
1952	58	----	69
1955	57	65	75
Mean	60	70	71
Garrison:			
1955	63	68	70
1956	61	----	----
1957	55	73	70
1958	57	70	70
1959	61	67	67
1960	59	74	69
Mean	59	70	69
Oahe:			
1959	75	75	75
1960	64	73	72
1961	70	72	79
1962	64	73	73
Mean	68	73	75
Francis Case:			
1954	79	79	77
1955	64	75	77
1956	73	79	79
Mean	72	78	78
Lewis and Clark:			
1956	72	77	77
1957	66	79	75
1958	70	79	80
1959	70	75	77
1960	70	77	75
1961	72	84	77
Mean	70	79	77

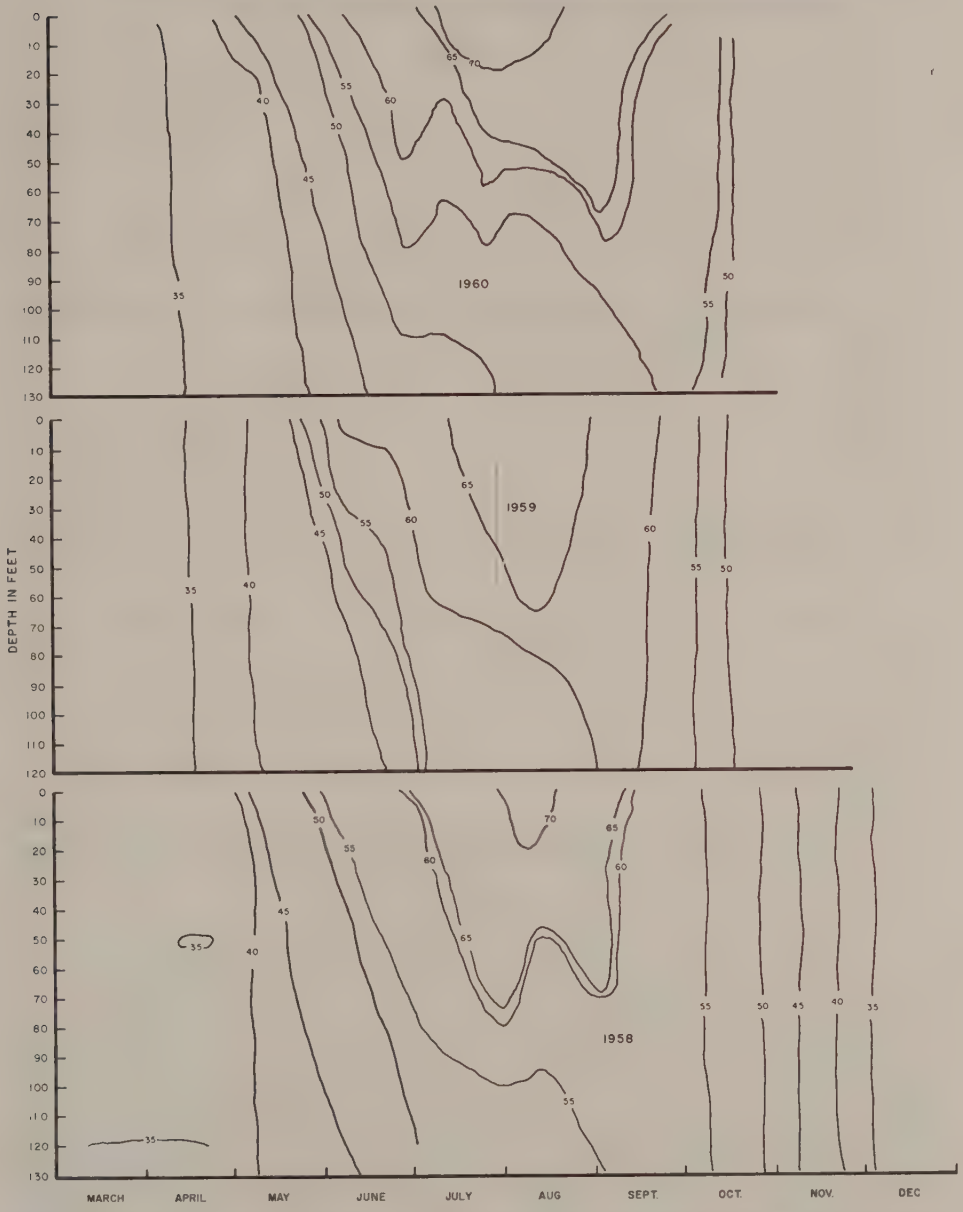

FIGURE 8.—Distribution of 5° F. isotherms 2.5 miles above Garrison Dam in 1958, 1959, and 1960.

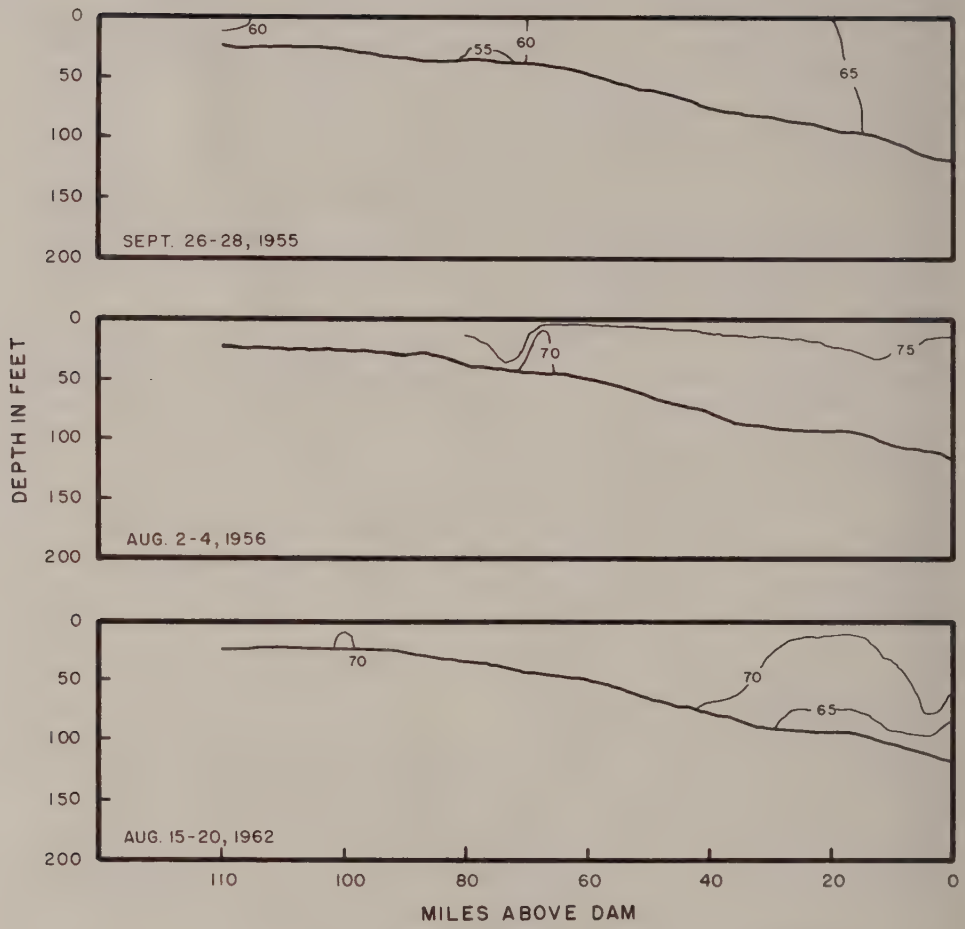

FIGURE 9.—Distribution of 5° F. isotherms in Lake Francis Case, 1955, 1956, and 1962.

usually mix the water strata within a few weeks. Oahe, with its higher outlet, is expected to stratify more distinctly than the other reservoirs. In Lake Francis Case, stratification rarely lasts over 2 weeks, owing to wind action. Because of heavy wind action the thermoclines in these reservoirs can best be described as "extended thermoclines" as illustrated by Hela and Laevastu (1961, p. 18). Examples of this type of thermocline development are shown in figure 10. Flushing action, shallow water, and wind action prevent stratification in Lewis and Clark Lake.

DENSITY CURRENTS

Subsurface currents may have significant influence on both biological activity (Wiebe, 1940) and sedimentation processes (Howard, 1960). Fort Peck has a morphometry most prone to development of subsurface currents because if its depth and thermal stratification, but Lake Sharpe may develop density currents for reasons mentioned earlier. The U.S. Army Corps of Engineers studied the distribution of water densities in Fort Peck in 1951 (fig. 11). Density equaled the sum of total dis-

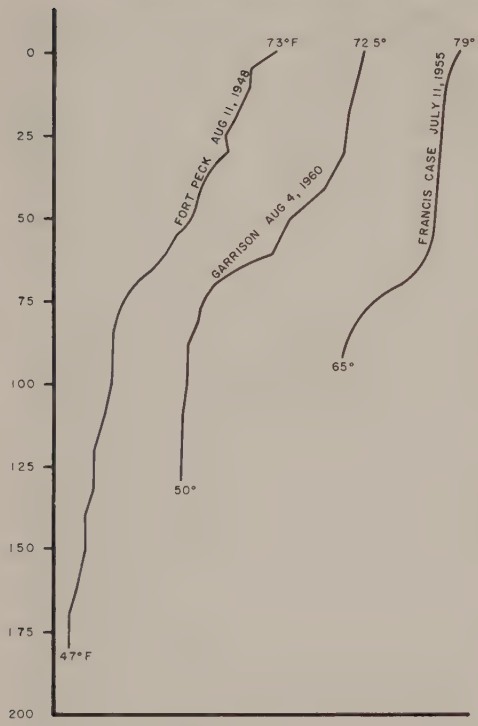

FIGURE 10.—Typical thermal stratification patterns in Missouri River main stem reservoirs.

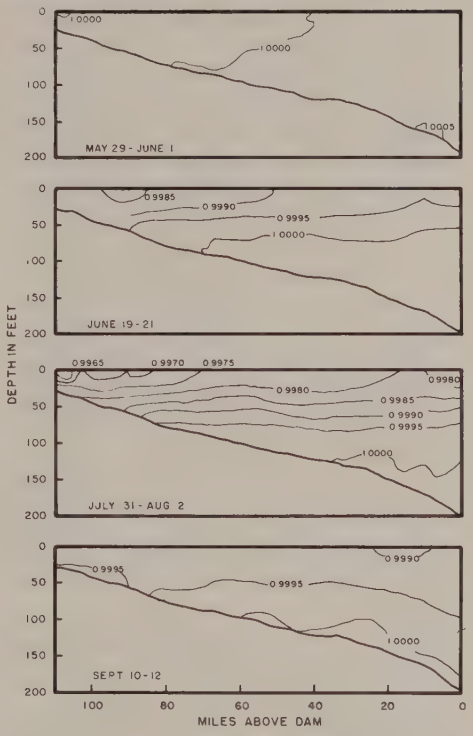

FIGURE 11.—Isocontours of water density in grams per cubic centimeter from Fort Peck Reservoir. Density equals the sum of suspended solids, total dissolved solids, and density of water at temperatures collected.

solved solids suspended sediment concentration, and water weight as calculated from temperature. The density in grams per cubic centimeter was then plotted by isocontours. No strong density currents were evident from these data, except in the upstream end during late July. Temperatures and dissolved solids measurements for this same period substantiated this observation (figs. 8 and 11).

Density currents have not been recorded in Garrison or Lake Francis Case except in the extreme upper ends for temporary periods. Most of the streams entering these reservoirs are warm and silt laden during the summer. The fact that the turbidity results from light soil particles rather than heavy particles may prevent silt-laden water from sinking. In addition, temperature stratification serves as a barrier. Evidence of density currents in this system was much less than observed at Lake Mead (Howard, 1960).

Stober (1963) recorded a density current the entire length of Tiber Reservoir (22,000 acres) located on an upstream tributary of the Missouri River above Fort Peck. It is probable that such currents will be more persistent in a small reservoir than in a large one. Churchill (1963) suggests this trend from his studies on TVA impoundments. Hembree, Krieger, and Jordan (1964) found more lateral than vertical mixing in Shadehill Reservoir in South Dakota because of stratification, but this condition was not measured on the main stem system.

TURBIDITY

All impoundments have strikingly reduced the turbidity of the Missouri River. Despite the fact that the muddiness of the Missouri has been documented since the expedition of Lewis and Clark, the river has never carried a heavy sediment load in terms of weight. Its high turbidity results from small, light, flattened clay particles which absorb light effectively. Neet at al. (1963) showed the differences in mean annual turbidities between inflow and outflow of Garrison and Lake Francis Case. Turbidities were reduced from 386 to 633 p.p.m. to less than 35 p.p.m. during 1955 and 1956. Similar influences were recorded below Lewis and Clark Lake at Yankton, S. Dak., at the water quality monitoring station of the U.S. Public Health Service.

Turbidities from the incoming Missouri River usually are significantly reduced within the upper 10 miles of an impoundment. Seasonal changes in p.p.m. of suspended sediment concentration were measured in Fort Peck in 1951 (fig. 12). Suspended sediment concentration is not alalways directly related to turbidity since it is a measurement of mass rather than light, but it may be assumed to reflect turbidity in this system. From June 14 to September 10, most of the reservoir had readings below 25 p.p.m. Similar changes were recorded at Francis Case and Garrison.

Although these changes are spectacular, the problems of turbidity are not as simple as these data indicate because of the fine soils of the entire basin, the persistent winds, and the shallowness of some of these reservoirs. Fluctuations in water level of Lake Francis Case had marked influence on turbidity levels near the upper end of the reservoir where silt had accumulated on the bottom (U.S. Public Health Service, 1956). As soon as water levels were low enough to expose these silt beds to wind-induced current action, turbidities increased in the area up to 2,000 p.p.m. Measurements were not taken downstream to determine how long this silt remained in suspension. Undoubtedly the upper reaches and mouths of tributary streams in each reservoir are influenced in the same manner. These temporary turbidities were also mentioned by Shields (1955) and Fogle (1961a). Such turbidities are undoubtedly detrimental both to fish spawning and to survival of eggs and young. This problem is particularly acute in shallow Lewis and Clark Lake where fine silt beds are continually exposed to wind action.

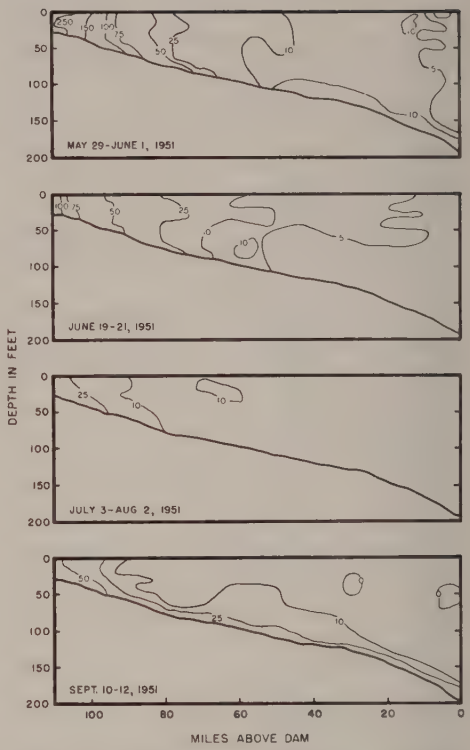

FIGURE 12.—Isocontours of suspended sediment concentration in p.p.m. in Fort Peck during 4 periods of 1951.

At the mouths of incoming streams, this problem will always be present. In Lake Francis Case, however, the fine particles

are being washed into the channel, and a rubble shoreline is developing. It is possible that water level management could be used to avoid exposing fine silt deposits to wave action during some critical periods in the life history of some fishes.

LIMIT OF VISIBILITY

Secchi disk readings give a rough measure of light penetration, and Verduin (1956) states that such readings can be assumed to indicate about one-fifth of the depth of the euphotic zone. Garrison readings (Needham, 1961) averaged 8.7 feet and ranged from 3.9 feet in Van Hook Arm to 13.3 feet near the face of the dam. No readings were taken in the upstream end of the reservoir and Van Hook Arm had an *Aphanizomenon* bloom at the time of measurement.

From June to August 1962, readings in the lower reaches of Lake Francis Case averaged 4.9 feet and ranged from 2.5 to 8.0 feet. Extensive data from all sections of Lewis and Clark Lake from 1962 to 1964 averaged 1.2 feet and ranged from 0.2 to 3.2 feet. The readings were greatest at the dam and decreased upstream (fig. 13).

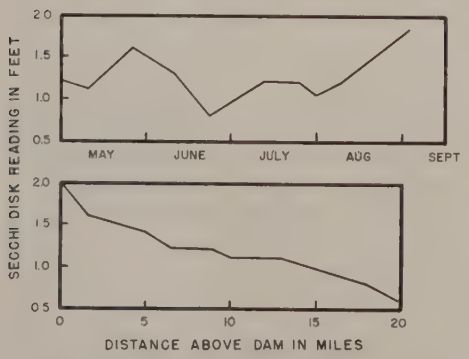

FIGURE 13.—Upper figure has average Secchi disk reading from 10 stations in Lewis and Clark Lake from May 1 to September 3, 1964. Lower figure has seasonal readings for each station in relation to its distance from dam in same period.

Seasonal changes from May 1 to September 3 showed a maximum reading in late May and early September. During the summer, Lewis and Clark Lake, with its east-west exposure, is continually exposed to southeast winds which stir up the shallow silt deposits. In addition, the high rate of flushing causes enough current to retain some particles in suspension.

WATER CHEMISTRY

The U.S. Public Health Service and the U.S. Geological Survey have collected detailed water chemical information on the Missouri River (U.S. Public Health Service, 1954, 1955, 1956, 1964; Neel, Nicholson, and Hirsch, 1963). In addition some studies related early impoundment of the river to changes in water chemistry. With the large amount of sedimentary surface deposits in the watershed and the unleached soils, both basin runoff and ground water aquifers contribute high quantities of dissolved solids to the water (table 7). High concentrations of calcium, sodium, sulfates, and bicarbonates reflect this geology. Some tributaries have sulfates in the 2,000 p.p.m. range. There is essentially no industrial pollution, and effects of domestic pollution are confined to sections immediately below municipalities. Only those dissolved gases and ions having known biological importance will be discussed.

Dissolved oxygen

Variation in percent saturation of dissolved oxygen is one of the best measurements available for depicting biological and chemical activity in a body of water. In the main stem reservoirs, surface measurements have averaged just below 100-percent saturation, with diurnal variations in the 80- to 120-percent saturation range (Neel, Nicholson, and Hirsch, 1963). Several vertical series at Fort Peck and Garrison have revealed oxygen deficits below 70 feet, although none was below 79-percent saturation and none lasted more than

20 days. Strong wind action and low rates of decomposition prevent severe oxygen deficits. Poddubnyy and Fortunatov (1961) stated that detritus-forming processes were less well developed in new reservoirs than in most natural eutrophic lakes.

TABLE 7.—*Concentrations of chemical constituents of the main stem Missouri River water within the impounded section of the river.*

[Analyses in parts per million, except where noted]

Chemical constituent	Minimum	Maximum
Silica (SiO_2)	4.1	24
Iron (Fe)	0	0.11
Calcium (Ca)	39	73
Magnesium (Mg)	10	30
Sodium (Na)	22	76
Potassium (K)	2.7	6
Bicarbonate (HCO_3)	136	245
Sulfate (SO_4)	69	250
Chloride (Cl)	2.4	13
Fluoride (F)	.4	.8
Nitrate (NO_3)	.17	1.9
Boron (B)	.07	.19
Dissolved solids, residue at 180° C.[1]	205	627
Hardness as $CaCO_3$, Ca, and Mg	139	280
Specific conductance at 25° C. in microhms per cc.[1]	365	876
pH in regular units	7	8.5
Phosphorus (P)	.01	3.15
Carbonate (CO_3)	.0	10.0
Nitrite (NO_2)	.001	.005
Ammonia nitrogen	.0	.23
Organic nitrogen	.50	1.36
Trace elements:		
Selenium (Se)*	.01	.01
Cadmium (Cd)	.01	.02
Barium (Ba)	.03	.03
Beryllium (Be)*	.0002	.0003
Lead (Pb)*	.02	.02
Chromium (Cr)*	.004	.005
Tin (Sn)*	.008	.01
Antimony (Sb)*	.04	.05
Manganese (Mn)*	.02	.02
Nickel (Ni)*	.008	.01
Bismuth (Bi)	.02	.03
Molybdenum (Mo)	.008	.01
Vanadium (V)	.008	.01
Copper (Cu)	.05	.20
Zinc (Zn)*	2	2
Cobalt (Co)*	.008	.008

[1] Higher readings have been recorded in the upper sections of tributaries.

*Trace elements indicated by asterisks were analyzed by spectrographic methods and are subject to error (See U.S. Public Health Service, 1962).

Supersaturated concentrations were commonly found below the dams at Garrison and Lake Francis Case. Supersaturation below Lake Francis Case was found by Neel, Nicholson, and Hirsch (1963) to be caused by air entrapment in the outlet tunnels. Shields (1956) recorded oxygen concentrations as low as 24 percent saturation in Lake Francis Case for short periods. Fogle (1963b) recorded 1 percent saturation at the bottom in the upper reaches of the impounded section of Oahe in 1962. He did not record low oxygen near the dam in deeper water. There is reason to believe that Oahe may develop sustained deficits when it reaches the operating range because the powerhouse intake is 125 feet above the bottom and because the deeper water will be below the influence of the wind.

Thermal stratification in Lewis and Clark is rare, and no dissolved oxygen deficits have been recorded in the open water. Measurements with a polyethylene bag on the bottom (Fremling and Evans, 1963) showed that a deficit developed at the mud-water interface of Lewis and Clark Lake. Further research will be necessary to understand the significance of these measurements although Fremling and Evans (1963) found that oxygen deficiencies in this habitat prevented development of *Hexagenia* populations.

Weekly measurements (taken at 10 a.m. on Monday) of dissolved oxygen are made at the Yankton water plant, 5 miles below Gavins Point Dam. These readings showed an upward trend in percent saturation from 1958 to 1962 (U.S. Public Health Service, 1964). This trend is directly related to increased diatom abundance.

Alkalinity

Most alkalinity is in bircarbonate form. Carbonate measurements rarely exceeded 8.5 p.p.m. In addition to the carbonate produced by photosynthesis, Neel, Nicholson, and Hirsch (1963) calculated, leaching of the numerous alkali deposits in the watershed resulted in readings of 0.1 to 6.0 p.p.m. during low water stages. Occasional carbonate readings of 10.0 p.p.m. were found during periods of high diatom abundance, with pH in the 8.3 to 8.5 range.

Bicarbonate alkalinities in a river system normally reach maximums during low flow and minimums during the flood season. Concentrations increase down-

stream because of additional soil leaching. Reservoir regulation upsets this trend in several ways. Alkalinity can be reduced when photosynthetic activity causes carbonate precipitation on the bottom. In Lake Francis Case, Neel, Nicholson, and Hirsch (1963) calculated, 2.67 percent of the alkalinity in the March 1-June 30, 1957, period was removed from solution by marl deposition. Also reservoirs serve as mixing basins which level out and delay normal seasonal trends. Data on inflow and outflow alkalinities from Lake Francis Case and Garrison Reservoir suggest that delays will range from 1 to 6 months (fig. 14). The decreases in alkalinity within a reservoir follow the "nutrient trap" concept as described by Cushing (1964). In the Montreal River lake-stream system in Saskatchewan, Cushing (1964) found that total dissolved solids and other essential ions for photosynthesis decreased down stream in direct relation to the increase in plankton. There was a much greater range in Garrison than in Lake Francis Case owing to its size and the diversity of its inflow. In a report covering stations at Williston, Bismarck, and Yankton from 1958 to 1962, the U.S. Public Health Service (1964) noted rising alkalinities at Bismarck and Yankton. Rising water levels in both Oahe and Garrison probably caused these increases. Limited data from Fort Peck suggest that alkalinities average about 30 p.p.m. less than in the lower reservoirs.

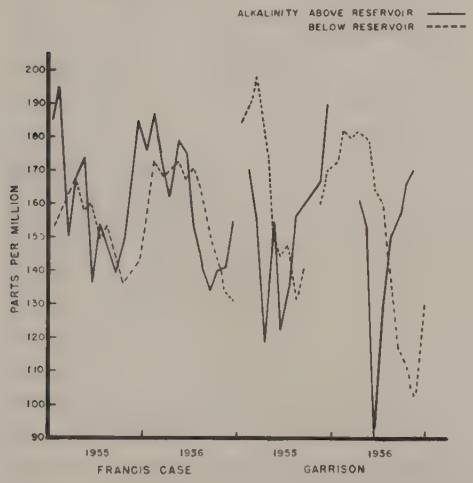

FIGURE 14.—Average monthly total alkalinity from surface above and below Lake Francis Case and Garrison in 1955 and 1956.

Sulfate

Sulfate concentrations in the Missouri River are high because of gypsum deposits in the basin. Measurements generally range from 100 to 250 p.p.m. with highest concentrations during low water in the winter and lowest during the spring high water period. Neel, Nicholson, and Hirsch, (1963) did not consider these concentrations important so far as phytoplankton production was concerned. Sulfate concentrations did not change significantly during the 1952–62 period (Neel, Nicholson, and Hirsch, 1963; U.S. Public Health Service, 1964).

There is a possibility that local concentrations of hydrogen sulfide could develop in shallow areas which serve as nurseries for young fish. Hayes (1964) and Siebruth (1960) reviewed several Russian papers where sulfate concentrations in reservoirs are similar to those in the Missouri Basin. Although sulfate reduction is possible in the aerobic zone, radioisotope studies showed that reduction occurred only in bottom sediments. Both deep and littoral bacteria-rich sediments were active in this reduction. Carbohydrate addition increased the rate. New reservoirs showed more vigorous activity than old reservoirs.

Total dissolved solids

Distribution of total dissolved solids (hereafter referred to as TDS) was measured extensively in Fort Peck and Garrison reservoirs by the U.S. Army Corps of Engineers in sedimentation studies. From knowledge of the chemical composition of

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the water we can assume that most of the change in TDS concerned calcium, sodium, magnesium, carbonates, and sulfates.

The concentration of TDS in Fort Peck increased from the headwaters to the dam up to August (fig. 15). In early September the concentrations were lowest in the middle and highest at each end. Differences between the upper and lower ends of the reservoir were about 150 p.p.m. in June and July. By mid-September, the differences by section of reservoir were less distinct. Data from 1950 were similar to 1951. Anderson and Pritchard (1951) recorded similar patterns on Lake Mead.

Garrison Reservoir had higher TDS readings than Fort Peck (figs. 16 and 17). The readings tended to increase toward the dam, but local influences from incoming streams were more striking than in Fort Peck. The highest concentrations (748 p.p.m.) were recorded in the headwaters of the Little Missouri Arm but these were diluted before they entered the main body of the reservoir. Highest readings were recorded in the spring and fall. The extreme variations in Garrison are due to the arid unleached soils, which quickly yield solutes to flowing water. Hembree, Krieger, and Jordan, (1964) found, in a small drainage area south of Garrison Reservoir, that differences of 170 to 1,200 p.p.m. of TDS can be expected in this geological area from differences in flow rate alone.

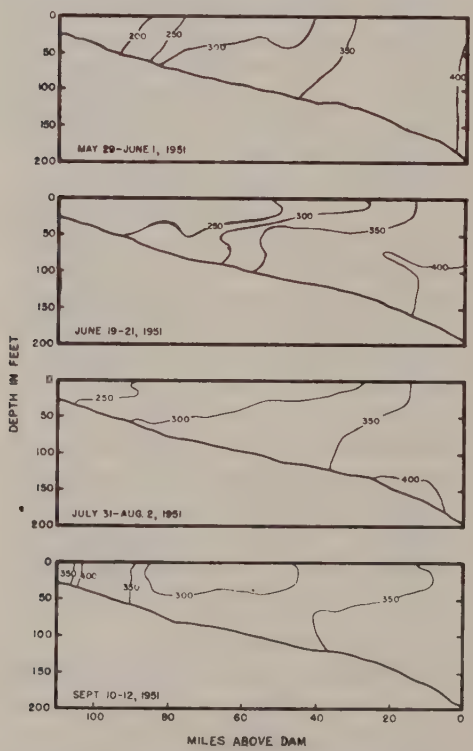

FIGURE 15.—Isocontours of total dissolved solids in Fort Peck Reservoir during 4 periods of 1951.

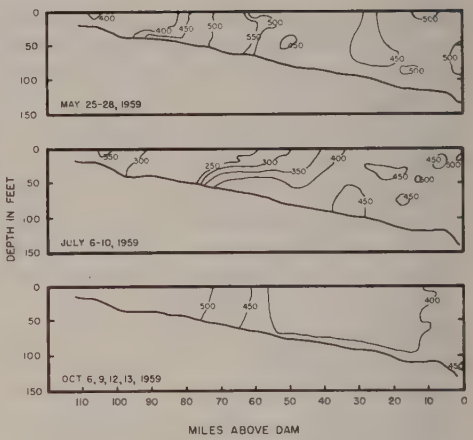

FIGURE 16.—Isocontours of total dissolved solids in Garrison Reservoir during 3 periods of 1959.

TDS in the Missouri River from Garrison Dam to Gavins Point Dam have not been measured as completely as in Fort Peck or Garrison, but readings in 1957–58 at Pierre and Yankton ranged from 377 to 627 and averaged 444 (U.S. Geological Survey, 1962). Seasonal differences were greater at Pierre than at Yankton, probably because Oahe Reservoir had not been impounded.

Hydrogen ion concentration

Most surface pH readings, which were not influenced by pollution or photosyn-

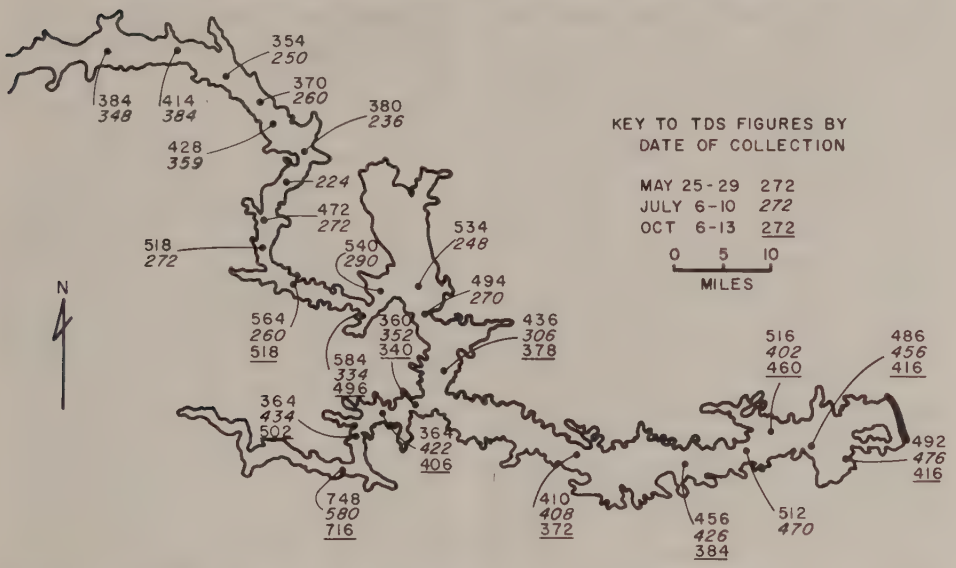

FIGURE 17.—Surface readings of total dissolved solids in p.p.m. during 3 sampling periods in Garrison Reservoir in 1959.

thetic activity, ranged from 8.0 to 8.3. Some low recordings, such as 7.0, were made below pollution effluents or at great depths. Readings up to 8.5 have been made during periods of high phytosynthetic activity. Up to 1955 all records were relatively stable, a fact that indicates a low rate of organic decomposition (Neel, Nicholson, and Hirsch, 1963). Records from 1958 to 1962 show an increased diurnal and seasonal variation, which indicates increased rates of organic decomposition and photosynthetic activity. Ranges were as follows: Yankton 7.8 to 8.5, Bismarck 7.9 to 8.5, and Williston 7.9 to 8.6 (U.S. Public Health Service, 1964).

Nitrogen

Extensive measurements of organic nitrogen, ammonia nitrogen, nitrites, and nitrates in Garrison and Lake Francis Case in 1955 and 1956 showed that neither reservoir influence the abundance of any form consistently (Neel, Nicholson, and Hirsch, 1963). Readings were generally higher in Garrison than in Lake Francis Case.

Phosphorous

Total phosphorous was always present, although soluble phosphorous (phosphate) was found in measurable quantities only at Williston and Bismarck (Neel, Nicholson and Hirsch, 1963). The phosphorous cycle in these reservoirs has not been studied.

Other elements

Year-round measurements of calcium, magnesium, silica, flourine, sodium, copper, and zinc did not reveal that any of these constituents were deficient or in excess. Silica was rarely recorded below 8 p.p.m., which is considerably above the minimum requirements for most diatoms (Lund 1954, 1964). Lund (1964) found in Lake Windemere that the numbers of *Asterionella* were directly related to amount of silica although other nutrients were limiting factors during a few years; silica concentrations dropped during every

Asterionella bloom. Several *Asterionella* blooms at Yankton and at Francis Case were likewise associated with a drop in silica concentration (Neel, Nicholson, and Hirsch, 1963).

Discussion

Considering the geological nature of the watershed, lack of significant industrial or domestic pollution, and the amount of water chemical data available, it does not appear that any of the known essential ions for biological production are lacking in the Missouri main stem reservoirs. Damann (1951) reached the same conclusion before the construction of the Missouri River main stem impoundments. Many ions that are considered essential for biological productivity enter and leave a reservoir in about the same concentration. This fact leads one to believe that factors other than the ionic concentration of the water control biological production. The relations between ion concentration in water and algae production are rarely clear because of the complex nutritional requirements of algae. Provasoli and Pintner (1960) described the heterotrophic abilities and needs of algae and emphasized the importance of organic micronutrients, such as vitamins and organic acids. Abundance of the the latter constituents is rarely measured in the field.

PLANKTON

Intensive studies were conducted on the phytoplankton of this system because of the expected taste and odor problems that could develop with reduced turbidities (U.S. Public Health Service, 1954, 1955, 1956; Neel, Nicholson, and Hirsch, 1963). In addition, water quality monitoring stations at Williston, Bismark, and Yankton provided continuous data on plankton samples collected two times each month (U.S. Public Health Service, 1964). These data are concerned principally with phytoplankton, although recent unpublished studies on Lewis and Clark Lake indicated that zooplankton abundance is closely relative to phytoplankton. In this report, only the general trends, seasonal variations, and changes by reservoir will be treated.

As in most river systems, diatoms are the most abundant forms, although bluegreen algae are present. The most common diatom genera were *Melosira*, *Fragilaria*, *Asterionella*, *Navicula*, *Cyclotella*, and *Stephanodiscus*. The above studies showed these phytoplankton trends: (1) Species that bloomed in the upper parts of the system could be followed downstream; (2) intermittent river areas reduced plankton numbers in direct relation to the length of river between the impoundments; (3) a seeding of new species in a reservoir required several weeks for blooming to develop; and (4) local influences such as rainfall, nutrients from tributaries or runoff, and new genera from tributaries changed the general trends. Williams and Scott (1962) summarized diatom counts of the national water quality monitoring system. The medial number per milliliter in the impounded section of the Missouri River was lower than in the upper Mississippi, but above those from the Columbia Basin. Pulses of *Asterionella* were of longer duration on the Missouri River than on either the Mississippi or the Columbia.

Monthly changes in number of phytoplankton per milliliter on Lake Francis Case and Garrison Reservoir in 1954—56 showed that maximum numbers developed from April to June, and minimum numbers in July (table 8). A bloom develops in September each year. Under ice cover the counts were usually high. Lake Francis Case had greater average annual counts than Garrison, but the differences were not consistent. The unusually high numbers during spring shown for 1956 in both Lake Francis Case and Garrison were an unusual bloom of *Cyclotella*.

TABLE 8.—*Average number of phytoplankton collected per milliliter in Lake Francis Case and Garrison Reservoir by months, 1954, 1955, and 1956*

[From Neel, Nicholson, and Hirsch, (1963); represents 2 to 5 samples per month]

Month	Lake Francis Case			Garrison		
	1954	1955	1956	1954	1955	1956
January	101	225	127	----	425	124
February	306	323	225	----	206	47
March	266	436	5,534	----	415	27
April	472	258	6,487	----	711	3,628
May	1,781	1,116	614	----	264	1,067
June	1,029	104	102	----	23	49
July	12	46	42	35	31	19
August	331	401	227	92	20	12
September	167	390	52	95	69	15
October	42	269	116	145	173	450
November	105	59	153	232	106	82
December	232	82	99	437	48	51
Annual average	403	320	1,190	----	207	509

Neel, Nicholson, and Hirsch, (1963) considered turbidity to be the most serious deterent to phytoplankton development in the Missouri River main stem system. Current velocity did not appear to be limiting because the tailwaters below Fort Randall and Garrison dams developed greater numbers than the reservoirs when clear water was provided (U.S. Public Health Service, 1955, 1956). These tailwater concentrations were not due to the plankton's leaving the reservoirs, because the intakes were below the heavy production areas within the reservoirs. Saturation of oxygen frequently reached 125 percent because of heavy photosynthetic activity. Their studies did not include the collecting of plankton from different sections of the reservoirs. Recent unpublished data from Lewis and Clark Lake show that decreased velocities are associated with abundance of many zooplankton species.

Measurements of phytoplankton abundance at Bismarck and Yankton showed a gradual increase in number per milliliter from 1953 to 1961 (fig. 18). The increase at Yankton was much greater than at Bismarck. Rising water levels in Garrison and Oahe probably contributed to these increases (fig. 2).

Williams (1964) reviewed the relation between phytoplankton density and species diversity in the major waterways of the United States. Relative to the Missouri River, he stated that conditions of frozen soil were beneficial because turbidity was low. Relative to density of diatoms, on a 10-unit scale Yankton rated 6, Bismarck 3, and Williston 4.

Recent data from Lewis and Clark Lake show the seasonal trend cited above for phytoplankton to be true also for zooplankton (fig. 19). Zooplankton abundance was not studied in detail by the water quality studies, although limited data in 1952–53 (U.S. Public Health Service, 1954) suggested that the seasonal cycles of rotifers followed that of phytoplankton closely.

BOTTOM FAUNA

Except for limited observations by Needham (1961) on Garrison Reservoir and Schmulbach and Sandholm (1962) on Lewis and Clark Lake, little is known concerning the bottom fauna of this system. Schmulbach and Sandholm (1962) recorded low standing crops on Lewis and Clark Lake in 1960. Recent studies show that populations of *Hexagenia* have increased from 11 kilograms per hectare in 1962 to 29 in 1964. In addition, large populations of chironomids have been found on submerged trees, and an increased abundance of *Polygonum* will be beneficial to many bottom animals. Judging from published reports on bottom fauna on other reservoirs, Lewis and Clark Lake and Lake Sharpe should develop good populations, while the other reservoirs may have low standing crops. The water level fluctuations of Garrison and Oahe may be of such a long-term nature, however, that littoral populations could develop. In addition, a deep water fauna may evolve.

Wiebe (1960) stated that storage reservoirs of the TVA system fluctuate and

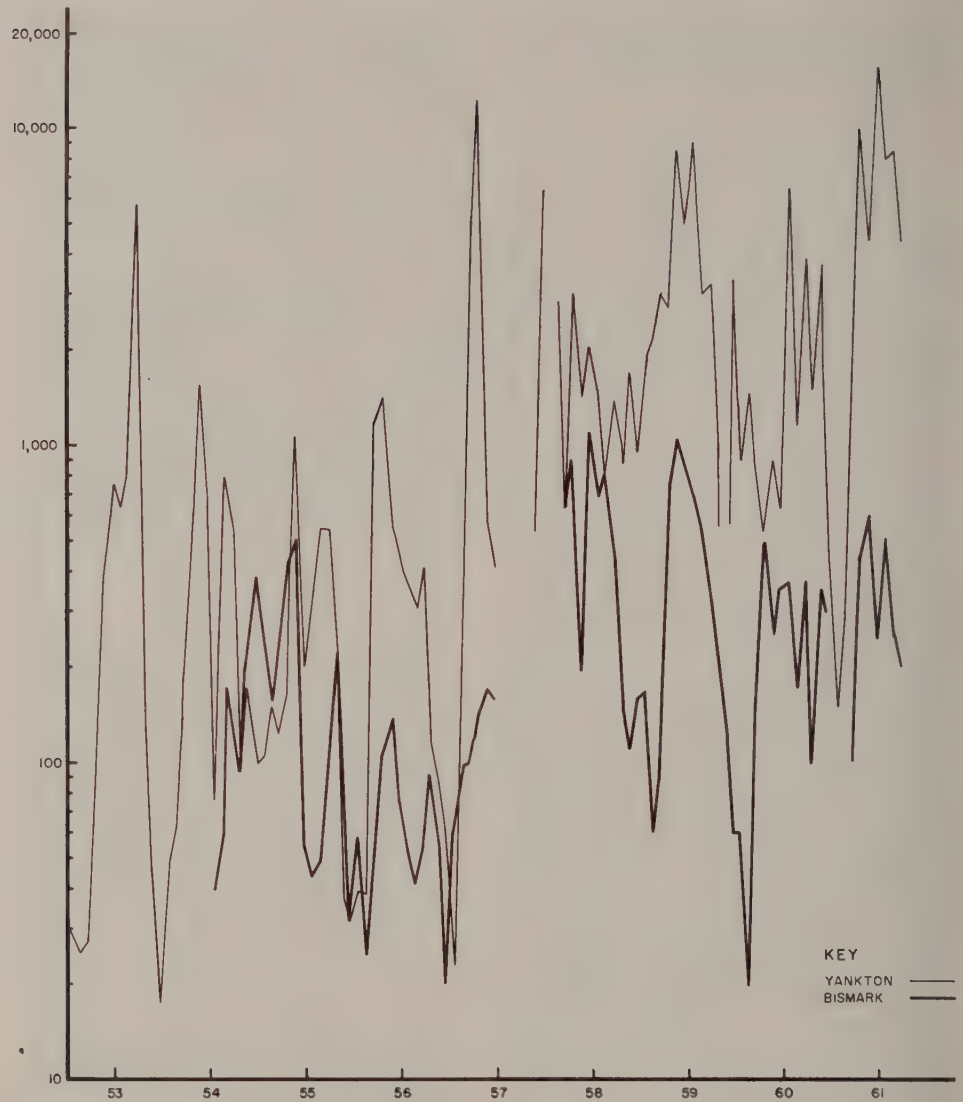

FIGURE 18.—Average number of phytoplankton per millimeter by months at Bismarck 1954–61, and Yankton 1953–61. Monthly averages represent 1 to 3 measurements. Data to June 1957 from Neel, Nicholson, and Hirsch (1963) and later data from National Water Quality Network Tables.

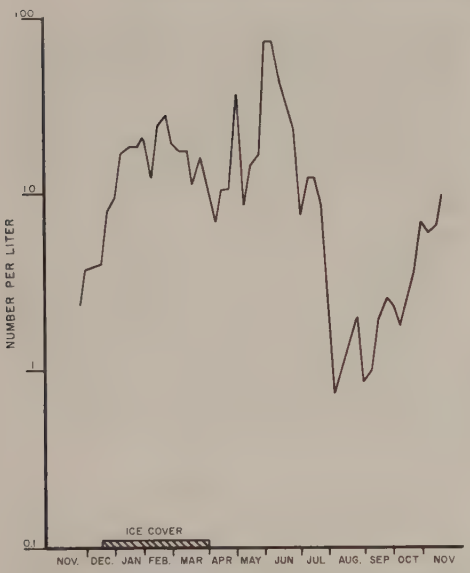

FIGURE 19.—Zooplankton densities in Lewis and Clark Lake from November 1963 to November 1964 as measured by automatic plankton sampler.

stratify to such a degree that bottom fauna is essentially restricted to a few species that can exist under anaerobic conditions. The TVA main stream reservoirs have significant populations of mayflies and other organisms because they do not stratify and have minor fluctuation in water levels.

Poddubnyy and Fortunatov (1961) reviewed benthos studies on Russian plains reservoirs. Significant observations were as follows: (1) Low biomass of benthos was due to low food supply for invertebrate detritus eaters since detritus-forming processes are less developed in reservoirs than in natural lakes; (2) low benthos was not due to heavy fish predation because thinning out of benthos consumers did not increase the biomass of benthos. They also reviewed the effects of submerged trees on bottom animal production and concluded the following: (1) Submerged forests serve as a substantial reserve for increasing the food base of fish; (2) the inundated trees, despite an abundance of invertebrate fauna, are almost totally unused by valuable fish for grazing; (3) on flooded forest remains *Dreissena* (mollusk) become abundant and the young *Dreissena* serve as important food for roach and ide (cyprinids), but valuable fish fail to utilize this organism; (4) flooded forests serve as spawning substrate for low-value fish; and (5) inundated forests serve as a refuge for both young and adult fish. The above authors did not consider a large number of trees to be a positive gain in the reservoir economy.

Grimas (1965) reviewed 10 years of study on the effects of impoundment on bottom fauna in reservoirs of Sweden. His major findings relative to reservoirs with large water level fluctuations were as follow: (1) Below the drawdown limit, redisposition of sediments and freezing conditions in winter reduced the number of bottom animals significantly; (2) the bottom area above the drawndown limit or the normal rich littoral zone is virtually depleted of bottom fauna; (3) trees and isolated clumps of detritus contained a much richer fauna than other areas; (4) chironomids, rare immediately after impoundment, became quite abundant in deep areas after the bottom sediments stabilized in about 10 years; (5) an abundant benthic cladoceran fauna was temporary; (6) the normal spring abundance of bottom animals, when fish normally feed intensively, is lacking; and (7) fishes that are dependent upon bottom fauna showed decreased growth and condition. His limited studies on river reservoirs, which do not straify thermally, and where the water level does not fluctuate significantly, showed a complex environment with a rich bottom fauna and high production.

FISH POPULATIONS

The fish populations of these reservoirs were studied to document major changes in growth rates, relative abundance, reproduction, and species composition for management purposes. The material presented includes fish species present, methods of sampling, relative abundance of common species, depth and areal distribution, growth rates, year-class strength, forage fish abundance, sport fish catch, and commercial catch.

FISH SPECIES

From the Missouri River main stem impoundments 59 fish species have been identified (table 9). Many of these species are remnants of the original river or tributary fauna and have become rare or may have disappeared. The white bass, rainbow trout, kokanee, and lake trout are introductions. The common species of large fish in the system, but not necessarily in each reservoir, are bigmouth buffalo, smallmouth buffalo, carp, river carpsucker, northern pike, channel catfish, shovelnose sturgeon, goldeye, sauger, black crappie, white crappie, walleye, yellow perch, shortnose gar, paddlefish, and freshwater drum. The collection and identification of small fish was not carried out in the same detail on all reservoirs, and the list is undoubtedly incomplete. Systematic terminology of Bailey and Allum (1962) has been followed whenever there were problems of synonomy. Unique fish collection records, reasons for some records, and major changes within the system are described below.

Fort Peck

Several mountain streams in proximity to this impoundment are responsible for the presence of brown trout, mountain sucker, longnose sucker, and lake chub in Fort Peck. In addition, lake trout and kokanee have been introduced, but their success has not been evaluated. Collections from Fort Peck do not include white crappie or bluegill, which are common in the lower reservoirs, although Brown (1962) lists these species in the Missouri drainage of Montana and they are probably present in Fort Peck.

Garrison

Walleye and white crappie are common, and this reservoir has most of the species present in the lower impoundments. The quillback was collected in the early years of impoundment but has not been taken since 1959.

Oahe

White bass and largemouth bass become common. A single gizzard shad was collected in 1955 (Carufel and Witt, 1963) in the Garrison tailwater, before the impoundment of Oahe, but none has been collected since.

Lake Francis Case

Gizzard shad reach their northernmost distribution here.

Lewis and Clark Lake

The longnose gar has been collected but is rare. Yellow perch, northern pike, burbot, and goldeye are less common than in the upstream reservoirs.

FISH SAMPLING METHODS

Fish sampling conducted on these reservoirs by State fishery agencies was designed to measure species abundance. There were variations in effort expended, sampling design, and gears used. The most common gear for capturing adult fish was a 250-foot nylon gill net, constructed of successive 50-foot panels of 1.5, 2, 2.5, 3, and 4 inches stretch measure. Except for Fort Peck, each reservoir was divided into sampling areas from the dam to the upper end of the impounded area. Sampling was usually conducted during late June, July, and August by a two- or

three-man crew. Most depths were sampled, although this gear could not be used where there was significant current. The standard catch per unit by South Dakota was an overnight set. In North Dakota the data are expressed by hours, although the daily schedule was similar to that used in South Dakota. For purposes of comparison, I have converted all Garrison Reservoir catches to overnight net sets rather than hours.

Recent studies by McCombie and Fry (1960) indicate that gil nets may give a representative sample of the population as long as selectivity is recognized. Moyle, Kuehn, and Burrows (1950) compared gill net data with large seine hauls and reached the same conclusion. Miller and Kennedy (1948) considered "localities" to be more meaningful for monitoring fish populations in large lakes with gill nets than the entire lakes as units. Although their con-

TABLE 9.—*Fishes collected in Missouri River main stem reservoirs*

[Relative abundance categorized as rare (R) or common (C); common names from American Fisheries Society Special Publication No. 2 (1960).]

Scientific name	Common name	Abundance in—				
		Fort Peck	Garrison	Oahe	Francis Case	Lewis and Clark
Scaphirhynchus albus (Forbes and Richardson)	Pallid sturgeon		R	R	R	R
Scaphirhynchus platorynchus (Rafinesque)	Shovelnose sturgeon	C	C	C	C	C
Polyodon spathula (Walbaum)	Paddlefish	C	C	C	C	C
Lepisosteus osseus (Linnaeus)	Longnose gar					R
Lepisosteus platostomus (Rafinesque)	Shortnose gar		C	C	C	C
Dorosoma cepedianum (LeSueur)	Gizzard shad				C	C
Alosa chrysochloris (Rafinesque)	Skipjack				R	
Salmo gairdneri (Richardson)	Rainbow trout	R	R		R	R
Salmo trutta (Linnaeus)	Brown trout	R	R			
Oncorhynchus nerka (Walbaum)	Kokanee	R				
Salvelinus namaycush (Walbaum)	Lake trout	R				
Esox lucius (Linnaeus)	Northern pike	C	C	C	C	R
Hiodon alosoides (Rafinesque)	Goldeye	C	C	C	C	R
Cyprinus carpio (Linnaeus)	Carp	C	C	C	C	C
Semotilus atromaculatus (Mitchill)	Creek chub		R	R		
Semotilus margarita (Cox)	Pearl dace		R			
Notemigonus crysoleucas (Mitchill)	Golden shiner		R	R	R	R
Hybopsis gracilis (Richardson)	Flathead chub	C	C	C	C	R
Hybopsis plumbea (Agassiz)	Lake chub	R	R			
Hybopsis storeriana (Kirtland)	Silver chub					R
Hybopsis gelida (Girard)	Sturgeon chub			R		
Rhinichthys atratulus (Hermann)	Blacknose dace			R		
Notropis stramineus (Cope)	Sand shiner		R		R	R
Notropis blennius (Girard)	River shiner			R		
Notropis illecebrosus (Girard)	Silverband minnow			R		
Notropis atherinoides (Rafinesque)	Emerald shiner		C	C	C	C
Notropis lutrensis (Baird and Girard)	Red shiner		C			R
Hybognathus nuchalis (Agassiz)	Silvery minnow	C				R
Pimephales promelas (Rafinesque)	Flathead minnow	C	C	C	C	R
Cycleptus elongatus (LeSueur)	Blue sucker	R	R	R	R	R
Ictiobus cyprinellus (Valenciennes)	Bigmouth buffalo	C	C	C	C	C
Ictiobus bubalus (Rafinesque)	Smallmouth buffalo	C	C	C	C	C
Carpiodes cyprinus (LeSueur)	Quillback		R			
Carpiodes c. carpio (Rafinesque)	River carpsucker	C	C	C	C	C
Moxostoma m. macrolepidotum (LeSueur)	Northern redhorse		C	C	C	C
Catostomus commersoni (La cépède)	White sucker	C	C	C–R	R	R
Catostomus catostomus (Forster)	Longnose sucker	R	R			
Pantosteus platyrhychus (Cope)	Mountain sucker	R				
Ictalurus melas (Rafinesque)	Black bullhead	R	R	R	R	R
Ictalurus punctatus (Rafinesque)	Channel catfish	C	C	C	C	C
Ictalurus furcatus (LeSueur)	Blue catfish			R		R
Noturus flavus (Rafinesque)	Stonecat	R	R	R	R	R
Pylodictus olivarus (Rafinesque)	Flathead catfish			R	R	R
Noturus mollis (Hermann)	Tadpole madtom		R			
Lota lota (Linnaeus)	Burbot	C	C	C	C	R
Roccus chrysops (Rafinesque)	White bass			C	C	C
Micropterus s. salmoides (La cepede)	Largemouth bass			C	C	C
Lepomis cyanellus (Rafinesque)	Green sunfish			R	R	R
Lepomis gibbosus (Linnaeus)	Pumpkinseed		R			
Lepomis humilis (Girard)	Orangespotted sunfish		R	R	R	R
Lepomis macrochirus (Rafinesque)	Bluegill		R	R	R	R
Pomoxis annularis (Rafinesque)	White crappie		C	C	C	C
Pomoxis nigromaculatus (Le Sueur)	Black crappie	C	C	C	C	C
Stizostedion canadense (Smith)	Sauger	C	C	C	C	C
Stizostedion v. vitreum (Mitchill)	Walleye	C	C	C	C	R
Perca flavescens (Mitchill)	Yellow perch	C	C	C	C	R
Etheostoma exile (Girard)	Iowa darter	R			R	
Aplodinotus grunniens (Rafinesque)	Freshwater drum	C	C	C	C	C
Eucalia inconstans (Kirtland)	Brook stickleback		R			

clusion is probably true, the nature of the data available on these reservoirs makes it advisable to group the data by reservoir. Hile (1962) analyzed the relations between time of set and catch of stationary gears (gill and trap nets) on the Great Lakes commercial fishery. He found that the most precise catch-per-unit-of-effort measurement resulted from calculating a catch-on-time regression but that the straight catch-per-lift statistic did not differ significantly from the catch-per-lift adjusted for time. This was true because of the limited mean variation in time of sets.

Frame nets, as described by Shields (1955), with 2.5-inch stretch mesh were used commonly in South Dakota and to a lesser extent in North Dakota. This gear was used only in shallow water where there was little current. The single lead is commonly attached to the shore. Kelly (1953) reported catches of this gear from the upper Mississippi River near LaCrosse, Wis., and considered this gear to be quite nonselective; poorest catches for most species were made during late June, July, and August, when the data in this report were collected. Nylon bag seines, 40 feet with ¼-inch mesh were used to sample small fish along the shoreline, and catch data are expressed in acres seined.

None of these gears sampled the limnetic zone or areas where strong current was present. From data collected from 1962 to 1964 on Lewis and Clark Lake, and from commercial catches in Lake Francis Case, it is known that large bigmouth and smallmouth buffalo, freshwater drum, burbot, paddlefish, and catfish are not sampled effectively by these gears.

The length frequencies of the common species collected by gill and frame nets show that, except for northern pike and sauger, few fish above 20 inches in total length were captured (fig. 20). Northern pike and sauger have a smaller girth than other species (carp and bigmouth buffalo) that are known to occur in abundance above 20 inches in length. The smaller girth allowed northern pike and sauger above 20 inches to be captured with the gear used. Depth distribution by species was measured by gill nets set on the bottom.

A limited number of scaled fish were aged in some years. All back-calculations assumed a straight-line body-scale relation; most scales were read by placing dry scales between glass slides and projecting the images with a 35-mm. slide projector. The number of various lengths of fish to be aged was determined arbitrarily from length-frequency curves, and more fish were aged in the abundant length groups than in the rare length groups. Methods for creel census are described in the cited reports.

FISH DISTRIBUTION WITHIN RESERVOIRS

Knowledge of the distribution of some fish species within these reservoirs is available from catch data of gill and frame nets. The following limitations must be recognized in these data: (1) Both gears are selective by size and species of fish; (2) all data were collected during the summer; (3) habitats with strong currents were not sampled; and (4) habitats where fish were captured were not described in detail. The gross area and depth distributions of some species are described.

Area distribution

Changes in relative abundance of species from the dams to the uppermost impounded areas have been recorded in Garrison and Lake Francis Case from June to August (Shields, 1955, 1956, 1957a; Sprague 1959a, 1961a, 1961b, 1963). Cer-

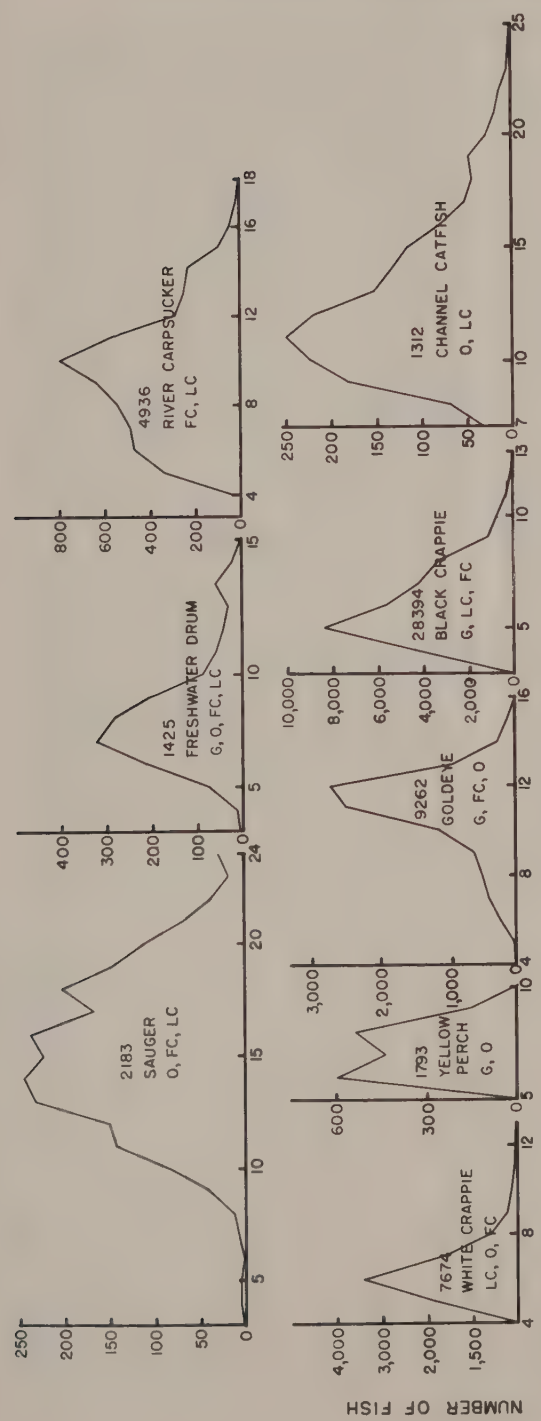

FIGURE 20.—Length frequencies of common fish species captured by gill nets and frame nets in Garrison (G), Oahe (O), Francis Case (FC), and Lewis and Clark (LC). Number of fish and reservoirs where data derived included.

tain trends applied to these reservoirs as follows:

Northern pike—no uniform distributional pattern.
Goldeye—no uniform distributional pattern.
Carp—common throughout but most abundant in upper end where current present.
White crappie—abundant wherever brush and cover present.
Black crappie—similar to white crappie but more common in shallow water.
Walleye—most abundant in upper end.
Sauger—no uniform distributional pattern.
Freshwater drum—most abundant in upper end.

Depth distribution

Shields (1956, 1957a) and Phenicie (1950) recorded depth of capture of gill net catches during July and August in Lake Francis Case and Fort Peck Reservoir (table 10). All Fort Peck netting was near the dam while Francis Case netting covered the entire reservoir. None of the data indicated significant catches below 70 feet.

In Fort Peck, goldeye were most common near the surface, yellow perch in the 10- to 29-foot zone, and sauger in the 10- to 19-foot zone. In Lake Francis Case, goldeye were commonly caught in water less than 20 feet deep, but good catches were made to 49 feet. Sauger, channel catfish, carp, and river carpsucker were commonly captured at all depths above 70 feet. Yellow perch were captured in greatest number in the 30- to 49-foot zone. White crappie were captured most commonly in the 20- to 49-foot zone, while black crappie were commonly collected in the 0- to 20-foot zone. Frame net catches cited by Shields (1956, 1957a) showed that black crappie were captured more frequently than white crappies in the shallow net sets. Neal (1963) showed similar distribution patterns for black and white crappie in Clear Lake, Iowa.

RELATIVE ABUNDANCE

Gill and frame net catch data provided a rough measure of relative abundance as long as gear limitations are recognized. In this reservoir system, Oahe, Francis Case, and Lewis and Clark were sampled with 250-foot experimental gill nets during June, July, and August, while Garrison sampling was confined to July and Au-

TABLE 10.—*Catch per overnight gill net set, during July and August, of yellow perch, sauger, goldeye, carp, carpsucker, channel catfish, black crappie, and white crappie in Fort Peck Reservoir in 1949 and Lake Francis Case in 1955 and 1956*

Fish species and year of sampling	At depth of—						
	0–9 feet	10–19 feet	20–29 feet	30–39 feet	40–49 feet	50–59 feet	60–69 feet
Yellow perch:							
Fort Peck, 1949	0.1	1.4	1.6	0.3	0.2	0.1	
Francis Case, 1955		2.3	6.7	2.5	1.5	.5	
Francis Case, 1956	.3	3.6	3.9	25.0	9.0		0.8
Sauger:							
Fort Peck, 1949	.4	1.5	.3	.2	.2		
Francis Case, 1955	2.0	3.6	5.7	6.3	5.0	1.0	.3
Francis Case, 1956	9.0	4.8	10.0	9.8	9.0	3.0	1.8
Goldeye:							
Fort Peck, 1949	1.1	.4	.2	.1			
Francis Case, 1955	2.0	4.2	2.4	5.1	1.3	.5	.2
Francis Case, 1956	13.0	23.6	5.0	10.2	7.0		.4
Channel catfish:							
Francis Case, 1955		1.7	1.1	5.6	4.3	.5	.3
Francis Case, 1956	5.3	5.0	3.2	8.0	1.0	5.0	6.4
Carp:							
Francis Case, 1955	19.5	20.9	17.4	8.8	19.8	13.0	8.4
Francis Case, 1956	9.3	6.0	6.1	8.0	23.0	2.0	19.8
River carpsucker:							
Francis Case, 1955	.5	5.7	6.8	4.1	1.0	1.0	.5
Francis Case, 1956	9.3	3.2	8.4	.8	5.0	8.0	.8
White crappie:							
Francis Case, 1955	1.0	4.3	6.2	6.0	4.0		
Francis Case, 1956	3.3	.6	2.6	7.8	9.0		.2
Black crappie:							
Francis Case, 1955	.5	1.3	.8	.9			
Francis Case, 1956	8.0	3.6	1.4	1.8			

gust. The catch data are summarized in tables in the appendix. Fort Peck data are not directly comparable but will be referred to periodically. Frame net catch data are available from Oahe, Lake Francis Case, and Lewis and Clark Lake. The number of gill net sets per year by reservoir was not proportional to surface area; for example, Lewis and Clark Lake was sampled over 100 times more intensively than Garrison for several years.

For all species, Garrison Reservoir had the highest catch rate by number and weight (table 11). Oahe showed a continued decrease in catch per set. The slow filling of Oahe and later unpublished data from trap nets suggest that this trend is not indicative of the true status of the fish population, but reflects gear selectively. Lewis and Clark catches did not fluctuate in weight as did the other reservoirs because it reached maximum pool within a few months after dam closure. Many large northern pike and buffalo not sampled by gill nets are present in Francis Case and Garrison. The high catches at Garrison were principally goldeye, which are unusually vulnerable to this gear.

Northern pike

Northern pike abundance was highest in Oahe with good catches developing in Garrison (table 12). Catches were increasing in Francis Case. For all three reservoirs the numbers taken were below the mean numbers for Minnesota lakes (Moyle, Kuehn, and Burrows, 1950) and for the Upper Mississippi River near La Crosse, Wis. (Kelly, 1953), but Oahe showed higher mean weights for several years. The catches per frame net (appendix tables 3 and 4) were higher in Oahe but lower in Francis Case.

Sauger

Relative abundance of sauger was highest in Garrison and Lewis and Clark (table 13). In all reservoirs, catch per set fluctuated widely. Lewis and Clark Lake showed the highest overall abundance during the sampling period, Lake Francis Case the lowest.

TABLE 11.—*Average catch of all fish per 250-foot gill net set in Garrison, Oahe, Francis Case, and Lewis and Clark*

Period after dam closure	Garrison		Oahe		Francis Case		Lewis and Clark	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1 year			71.1	45.2			50.4	29.8
2 years			43.5	27.5	82.1	48.9	70.8	32.6
3 years			34.0	35.7	64.9	57.9	53.5	24.1
4 years			22.7	21.2			45.9	29.4
5 years							46.4	29.7
6 years	71.4	47.6			29.9	38.9	45.6	31.9
7 years	62.9	46.0					65.6	
8 years	80.6	56.3						
9 years	71.2	54.7						

TABLE 12.—*Average catch of northern pike per 250-foot gill net set in Garrison, Oahe, and Francis Case*

Period after dam closure	Garrison		Oahe		Francis Case	
	Number	Pounds	Number	Pounds	Number	Pounds
1 year			0.8	0.6		
2 years			7.0	11.2	0.1	0.3
3 years			.3	9.7	(1)	.1
4 years			.7	2.8		
5 years					.3	1.7
6 years	0.2	1.3				
7 years	.3	1.8				
8 years	.9	1.9				
9 years	.9	2.5				

[1] Less than 0.1.

TABLE 13.—*Average catch of sauger per 250-foot gill net set in Garrison, Oahe, Francis Case, and Lewis and Clark*

Period after dam closure	Garrison		Oahe		Francis Case		Lewis and Clark	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1 year			3.8	7.0	0.6	1.4		
2 years			1.3	1.4	1.3	1.3	3.8	3.4
3 years			4.2	3.2	1.0	.9	6.9	11.1
4 years			3.1	2.4	2.1	3.0		
5 years					3.0	5.3		
6 years	4.2	4.4			1.8	3.1	5.5	8.6
7 years	5.7	5.7			1.9			
8 years	4.5	4.3						
9 years	5.0	5.0						

Crappie

Black and white crappie have been grouped because they were not always separated by species (table 14). With gill net data alone, Garrison showed the most crappie. Lewis and Clark Lake had several strong year classes, but abundance decreased greatly after the first 4 years of impoundment. Lake Francis Case data also suggest a decrease in relative abundance. White and black crappie are vulnerable to gill nets and frame nets, and it is evident that fluctuations in abundance can be expected in these reservoirs. The frame net catch rates during the early years of impoundment were considerably higher than recorded by Kelly (1953) for the upper Mississippi River. Recent (1963–64) unpublished data from Oahe show a great increase of both species.

Yellow perch

Yellow perch were consistently more abundant in Garrison than in Oahe or Francis Case, but limited data from Fort Peck (appendix table 1) suggest high numbers there (table 15). A few were collected in Lewis and Clark Lake. The average weight was low for all reservoirs. Extreme fluctuations in abundance appear to be common. From Weatherley's (1963) discussion of the factors influencing the world distribution of perch, it is apparent that both turbidity and current may limit perch populations in Lewis and Clark Lake, and Lake Francis Case. Temperatures are not limiting factors in this system.

Goldeye

Goldeye are much more abundant in Garrison and Fort Peck than in the lower

TABLE 14.—*Average catch of black and white crappies per 250-foot gill net set and per frame net set in Garrison, Oahe, Francis Case, and Lewis and Clark*

Set and period after dam closure	Garrison		Oahe		Francis Case		Lewis and Clark	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Gill net:								
1 year			0.1				0.5	0.1
2 years			.6	0.1	5.8	1.1	3.8	.3
3 years			.5	.1	7.0	1.9	10.1	1.4
4 years							2.7	.5
5 years							2.5	.4
6 years	3.6	0.6			3.2	1.5	1.8	.3
7 years	4.0	1.3					1.7	
8 years	6.2	1.5						
9 years	7.1	1.8						
Frame net:								
1 year			3.3		18.0	2.4	7.2	1.0
2 years			1.1		50.9	9.7	115.1	8.1
3 years			.8		87.7	33.1	97.3	10.6
4 years			.1				51.6	5.4
5 years							7.8	1.7
6 years					14.1	.7	19.4	4.2
7 years							.9	

reservoirs (table 15 and appendix table 1). They are rare in Lewis and Clark but common in Oahe and Francis Case. The catch rates for Garrison and Fort Peck suggest that this species is maintaining its abundance.

Carp and river carpsucker

Carp were most abundant in Lewis and Clark Lake (table 16). Oahe and Francis Case showed a decrease in abundance during the period of sampling, while Garrison catches were constant.

River carpsucker were captured in greatest numbers and weight in Lewis and Clark Lake but relative abundance rarely approached that of carp in any reservoir (table 16). There appeared to be a general decrease in relative abundance of river carpsucker upstream from Lewis and Clark Lake to Garrison.

GROWTH RATES

Age and growth information on some common scaled fishes has been determined for Fort Peck, Garrison, Oahe, Lake Francis Case, and Lewis and Clark Lake. For comparing growth rates among reservoirs a few species were selected with contrasting food habits as adults. The species and their principal foods are as follows: (1) sauger, almost entirely predaceous on fish; (2) carp, principally bottom fauna

TABLE 15.—*Average catch of yellow perch and goldeye per 250-foot gill net set in Garrison, Oahe, and Francis Case*

Species and period after dam closure	Garrison		Oahe		Francis Case	
	Number	Pounds	Number	Pounds	Number	Pounds
Yellow perch:						
2 years			0.5	0.1	3.5	0.7
3 years			4.3	.6	7.2	1.8
4 years			5.0	.6		
6 years	7.7	1.9			1.1	.3
7 years	7.0	1.8				
8 years	4.0	.5				
9 years	8.1	1.5				
Goldeye:						
1 year			11.7	11.7		
2 years			1.0	.5	2.9	1.2
3 years			4.4	2.9	7.9	4.0
4 years			2.5	2.2		
6 years	36.5	18.2			4.3	3.1
7 years	29.5	14.8				
8 years	31.2	13.6				
9 years	41.7	20.8				

TABLE 16.—*Average catch of carp and river carpsucker per 250-foot gill net set in Garrison, Oahe, Francis Case, and Lewis and Clark*

Species and period after dam closure	Garrison		Oahe		Francis Case		Lewis and Clark	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Carp:								
1 year			45.6	16.8			21.1	6.4
2 years			15.9	6.9	16.6	16.6	29.1	7.0
3 years			10.9	10.9	10.8	15.7	10.8	7.9
4 years			3.5	5.0			20.9	9.0
5 years							18.4	7.3
6 years	7.3	8.4			5.9	11.3	17.4	7.9
7 years	5.5	8.2					16.7	
8 years	8.7	17.5						
9 years	7.4	12.0						
River carpsucker:								
1 year			1.2	1.5			1.8	2.5
2 years			1.0	.7	3.9	3.6	5.7	1.5
3 years			1.1	1.3	4.3	6.7	8.3	3.9
4 years			.6	.7			7.1	3.7
5 years							10.2	5.3
6 years	.2	.6			3.4	6.0	10.4	5.2
7 years	.4	.6					5.1	
8 years	1.4	3.3						
9 years	.5	1.1						

and zooplankton; (3) river carpsucker, mostly zooplankton with a small amount of phytoplankton and insects; (4) freshwater drum, bottom fauna and fish; and (5) goldeye, bottom fauna and fish.

Sauger

Vanicek (1964) compared sauger growth in Lewis and Clark Lake with that in other reservoirs and natural lakes. Except for Norris Reservoir in Tennessee, the Missouri River reservoirs showed the fastest growth. Among the Missouri River main stem reservoirs, Fort Peck showed the slowest growth and Lewis and Clark Lake the fastest (table 17). Lake Francis Case and Lewis and Clark Lake both have gizzard shad, which probably accounts for the rapid growth. The faster growth rate in the lower reservoirs appeared to extend through the fourth year of life. It appears that growth rate in Lewis and Clark and Francis Case is decreasing.

Goldeye

Claflin (1963) summarized growth data of goldeye from Lewis and Clark and the 60 miles of the river below the dam. He showed that goldeye from this area grew more rapidly than in most northern natural lakes, although slower than in Lake Texoma in Oklahoma (Martin, 1952). Among the main stem reservoirs, Lake Francis Case showed the best growth and Garrison the slowest (table 18). Goldeye were most abundant in Garrison and Fort Peck but were common in all reservoirs except Lewis and Clark. Growth was decreasing in Francis Case and Lewis and Clark, increasing in Oahe.

River carpsucker

Garrison Reservoir had the fastest growth recorded, followed in order by Francis Case, Oahe, and Lewis and Clark (table 19). Growth differences were evident for all age groups measured. Walburg and Nelson (1966) describe Lewis and Clark growth and attribute the slow growth in that reservoir to low food abundance.

Carp and freshwater drum

Carp in Francis Case showed the fastest growth, followed in order by Garrison, Oahe, and Lewis and Clark (table 20.) Growth was significantly slower in Lewis and Clark for all age groups. Walburg and Nelson (1966) documented the slow growth of carp in Lewis and Clark Lake and related the condition to low zooplankton and bottom fauna abundance.

Freshwater drum in Garrison Reservoir showed the fastest growth, followed by Francis Case, Lewis and Clark, and Oahe (table 21). Sampling of drum was weak.

YEAR-CLASS STRENGTH

Reproduction was measured several years by shoreline seining and small-mesh trap nets, but catches of young-of-the-year during July and August rarely agreed with age class distribution and abundance of adult fish. Therefore, only the age-group distribution of adult fish was used for comparing year-class strength.

Carp

Carp are commonly captured in all reservoirs, but strong year classes were produced most regularly in Garrison Reservoir (table 22). The gradual rise in water level of this reservoir created suitable spawning conditions for several years (fig. 2). In Oahe only the 1957 and 1958 year classes appear to be strong, and relative abundance decreased from 1959 to 1962 (table 14). In Lake Francis Case strong year classes were produced in 1953 and 1955, but relative abundance decreased by 1959 (table 14). In Lewis and Clark Lake the 1955 and 1956 year classes were strong, but there was no evidence of significant survival after that period. Relative abundance of significant survival after that period. Relative abundance also

decreased from 1956 to 1962 (Walburg, 1964). Except for Garrison, conditions for survival of carp in these reservoirs do not appear to be favorable.

There have been suggestions that some type of carp control might be necessary in these reservoirs. Although Shields (1958c) suggested that carp spawning and survival could be discouraged by water level manipulation in Lake Francis Case, it is doubtful whether carp in any reservoir have reproduced regularly enough to become detrimental to the more desirable species. Walburg and Nelson (1966) showed that successful year classes in Lewis and Clark Lake were produced only in years when there was a rising water level during the spawning period.

TABLE 17.—*Average calculated total lengths of sauger by year of capture from Fort Peck, Garrison, Oahe, Lake Francis Case, and Lewis and Clark Lake*

[Lengths in inches; number of fish aged in parentheses. Data from Peters, 1964; Carufel, 1961; Fogle, 1961a, 1961b, 1963a, 1963b; Nelson, 1961a, 1962a; Shields, 1955, 1957a, 1957b, 1958a, 1958b; Sprague, 1958, 1959a, 1959b, 1960, 1963. All data on growth and age-class composition which follow are taken from those reports]

Reservoir and year of capture	Average Calculated length at end of year—						
	1	2	3	4	5	6	7
Fort Peck:							
1948	5.1 (124)	8.8 (124)	11.7 (118)	14.3 (88)	16.9 (32)	19.4 (13)	20.5 (4)
1949	4.8 (134)	9.0 (129)	12.8 (109)	15.3 (77)	14.6 (44)	19.2 (11)	----------
Garrison:							
1960	7.9 (121)	12.4 (91)	15.6 (51)	18.3 (27)	21.4 (3)	25.1 (1)	----------
1962	6.1 (49)	10.4 (40)	14.1 (27)	17.5 (12)	20.4 (1)	----------	----------
Oahe:							
1959	6.9 (198)	11.4 (155)	14.4 (93)	16.7 (34)	18.8 (8)	----------	----------
1960	5.2 (159)	10.1 (142)	13.8 (117)	16.1 (61)	18.0 (24)	19.1 (4)	----------
1961	5.4 (181)	11.0 (143)	13.8 (45)	16.2 (20)	18.2 (8)	20.4 (3)	----------
1962	5.5 (149)	9.7 (133)	12.2 (61)	15.6 (14)	17.6 (5)	20.7 (1)	----------
Francis Case:							
1954	6.1 (19)	----------	----------	----------	----------	----------	----------
1955	5.4 (204)	12.0 (189)	----------	----------	----------	----------	----------
1956	6.5 (194)	12.3 (182)	17.0 (66)	20.3 (9)	----------	----------	----------
1959	6.1 (119)	10.7 (107)	15.3 (49)	18.9 (22)	20.6 (3)	----------	----------
Lewis and Clark:							
1956	6.8 (25)	13.2 (25)	16.8 (3)	19.3 (3)	----------	----------	----------
1957	7.3 (63)	12.6 (15)	16.0 (13)	19.6 (5)	----------	----------	----------
1958	8.7 (71)	13.1 (62)	16.1 (8)	----------	----------	----------	----------
1960	6.6 (109)	11.7 (109)	15.5 (103)	18.1 (74)	20.2 (6)	----------	----------
1961	7.7 (86)	11.4 (82)	15.1 (72)	17.8 (57)	19.9 (37)	21.9 (6)	----------

TABLE 18.—*Average calculated total length of goldeye from Fort Peck, Garrison, Oahe, Francis Case, Lewis and Clark, and Missouri River*

[Length in inches; number of fish aged in parentheses. See headnote, table 17, for references]

Reservoir and year of capture	Average calculated lengths at end of year—					
	1	2	3	4	5	6
Fort Peck:						
1949	4.6 (312)	8.8 (312)	11.2 (281)	12.3 (144)	13.3 (45)	14.1 (8)
1950	4.5 (12)	8.7 (11)	11.1 (8)	12.2 (3)	12.8 (11)	----------
Garrison:						
1960	4.3 (114)	8.0 (97)	10.2 (74)	11.8 (27)	12.7 (3)	----------
1962	4.4 (46)	8.0 (34)	10.4 (26)	11.7 (7)	12.8 (1)	----------
Oahe:						
1959	3.7 (9)	----------	----------	----------	----------	----------
1960	3.4 (34)	7.2 (30)	----------	----------	----------	----------
1961	4.8 (106)	8.6 (67)	11.5 (41)	----------	----------	----------
1962	4.8 (100)	9.3 (92)	11.6 (62)	13.0 (30)	----------	----------
Francis Case:						
1954	6.1 (31)	----------	----------	----------	----------	----------
1955	5.3 (143)	9.8 (98)	----------	----------	----------	----------
1956	4.7 (144)	9.9 (121)	12.2 (26)	----------	----------	----------
1959	4.5 (104)	8.9 (100)	11.7 (75)	12.8 (12)	----------	----------
Lewis and Clark:						
1956	6.7 (1)	----------	----------	----------	----------	----------
1958	6.3 (9)	9.8 (9)	12.9 (8)	----------	----------	----------
1960	4.2 (21)	8.1 (21)	10.9 (21)	12.9 (10)	----------	----------
Missouri River: [1] 1962–63	4.5 (266)	7.9 (261)	10.5 (259)	11.9 (223)	12.8 (124)	13.5 (34)

[1] Includes Lewis and Clark Lake and tailwater.

TABLE 19.—*Average calculated total lengths of river carpsucker from Garrison, Oahe, Francis Case, and Lewis and Clark*

[Lengths in inches; number of fish aged in parentheses. See headnote, table 17, for references]

Reservoir and year of capture	Average calculated length at end of year—				
	1	2	3	4	5
Garrison:					
1960	4.3 (16)	8.0 (16)	11.3 (14)	13.9 (10)	16.4 (4)
1962	3.8 (13)	8.1 (13)	11.6 (12)	14.9 (10)	17.1 (8)
Oahe:					
1959	2.3 (74)				
1960	4.1 (89)	6.6 (80)			
1961	3.7 (39)	7.4 (39)	10.0 (18)		
1962	3.6 (43)	7.2 (43)	10.2 (39)	12.2 (12)	
Francis Case:					
1954	5.2 (3)				
1955	2.8 (13)				
1956	2.6 (43)	6.8 (35)	10.7 (22)		
1959	3.2 (67)	7.1 (67)	10.8 (63)	13.6 (36)	
Lewis and Clark:					
1956	3.9 (88)				
1958	2.8 (90)	5.8 (90)	8.0 (88)		
1959	2.1 (133)	5.2 (133)	7.1 (133)	9.3 (124)	
1960	2.1 (132)	4.6 (132)	6.6 (128)	8.3 (127)	9.5 (97)

TABLE 20.—*Average calculated total lengths of carp from Garrison, Oahe, Francis Case, and Lewis and Clark*

[Lengths in inches; number of fish aged in parentheses. See headnote, table 17, for references]

Reservoir and year of capture	Average calculated length at end of year—				
	1	2	3	4	5
Garrison:					
1960	5.2 (37)	10.0 (37)	12.9 (36)	15.4 (20)	17.9 (4)
1962	4.1 (23)	8.8 (22)	12.8 (17)	14.6 (11)	16.1 (3)
Oahe:					
1959	3.6 (220)				
1960	4.5 (101)	6.9 (94)			
1961	4.1 (169)	8.5 (166)	11.9 (148)		
1962	3.2 (101)	7.1 (100)	11.0 (96)	13.3 (69)	
Francis Case:					
1954	6.5 (136)				
1955	5.7 (265)	10.9 (249)			
1956	5.4 (199)	10.7 (168)	13.7 (134)		
1959	5.5 (142)	9.9 (139)	18.8 (127)	15.7 (15)	
Lewis and Clark:					
1956	3.9 (139)				
1958	5.2 (128)	6.8 (127)	8.8 (61)		
1959	3.1 (148)	6.2 (148)	8.5 (147)	10.2 (76)	
1960	3.1 (124)	5.8 (124)	7.5 (124)	8.9 (117)	10.5 (31)

TABLE 21.—*Average calculated total lengths of freshwater drum from Garrison, Oahe, Francis Case, and Lewis and Clark*

[Lengths in inches; number of fish aged in parentheses. See headnote, table 17, for references]

Reservoir and year of capture	Average calculated length at end of year—				
	1	2	3	4	5
Garrison:					
1960	4.4 (12)	8.4 (12)	11.1 (11)	13.7 (4)	14.5 (1)
1962	4.9 (21)	7.8 (17)	10.4 (13)	12.4 (10)	13.4 (2)
Oahe:					
1959	2.8 (35)				
1960	2.7 (19)	5.7 (15)			
1961	2.8 (44)	4.6 (34)	6.2 (6)		
1962	2.8 (6)	5.4 (6)	7.9 (5)	12.3 (3)	
Francis Case:					
1954	4.1 (76)				
1955	3.7 (223)	6.8 (191)			
1956	3.5 (136)	7.0 (124)	9.3 (90)		
1959	3.4 (61)	6.3 (60)	8.7 (52)	10.8 (22)	12.6 (4)
Lewis and Clark:					
1956	3.9 (34)				
1958	3.6 (53)	7.7 (52)	11.0 (1)		
1959	3.1 (41)	6.2 (36)	8.7 (33)	11.5 (2)	
1960	3.0 (31)	6.0 (31)	7.8 (28)	8.7 (14)	

TABLE 22.—*Age distribution, in percent, of carp taken from Garrison, Oahe, Francis Case, and Lewis and Clark, selected years*

[See headnote to table 17 for references]

Reservoir and year of capture	Number aged	Percent in age group—							
		I	II	III	IV	V	VI	VII	VII+
Garrison:									
1960	37		3	43	43	8	3		
1961			11	48	40				
1962	23	1	5	23	42	25	3		
Oahe:									
1959	271	81	10	3	2	2	1	1	
1960	301	2	31	39	21	3	1	2	1
1961	230	1	8	64	20	3	1	2	1
1962	241	1	2	11	29	28	17	7	5
Francis Case:									
1954	203	67	11	13	7	(1)	(1)		
1955	324	5	77	11	6	1	1		
1956	212	15	16	63	4	1			(1)
1959	142	2	8	79	11				
Lewis and Clark:									
1956	223	63	5	18	7	5	1		1
1957	155	34	57	2	4	1	1		1
1958	143	1	46	43	7		2		1
1959	167		1	42	45	6	2		4
1960	145			5	59	21	8		7
1962	642		1		10	24	32		33

[1] Less than 1.

Goldeye

In Fort Peck, Garrison, and Oahe, year-class production of goldeye has been consistent (table 23). Francis Case and Lewis and Clark showed poor survival after several years of impoundment. Sprules (1954) stated that they are common in large turbid rivers in Canada where there are fine clay particles in suspension. They spawn in shallow flooded areas immediately after the ice leaves, but they do not require vegetation. The eggs of goldeye are semibuoyant, and a slight water movement will keep them in suspension (Battle and Sprules, 1960). The fact that eggs would be little affected by bottom type or water level fluctuation probably accounts for their ability to tolerate conditions in these impoundments.

TABLE 23.—*Age distribution, in percent, of goldeye taken from Fort Peck, Garrison, Oahe, Francis Case, and Lewis and Clark, selected years*

[See headnote to table 17 for references]

Reservoir and year of capture	Number aged	Percent in age group—						
		I	II	III	IV	V	VI	VII+
Fort Peck:								
1949	312		10	44	32	12	2	
1950	12	8	25	42	16	8		
Garrison:								
1960	114	8	23	62	6	1		
1961	75	7	19	22	42	8	2	
1962	46	21	19	57	33	(1)		
Oahe:								
1959	228	4	6	74	14	1		
1960	94	4	32	35	18	7	3	
1961	174	22	15	24	24	12	3	(1)
1962	131	6	23	24	23	14	7	2
Francis Case:								
1954	40	77	15	8				
1955	148	30	66	2	1			
1956	144	16	66	18				
1959	104	4	24	61	11			
Lewis and Clark:								
1956	81	1	11	58	23	5	1	
1957	53		9	45	30	13	2	
1958	32		3	25	34	22	12	3
1960	29			46	26	9	9	
1961	14				50	28	14	7
1962	41				2	24	44	30

[1] Less than 1.

River carpsucker

This species has produced strong year classes more consistently than carp in Oahe, and has produced consistent year classes in Garrison. Strong year classes in Francis Case and Lewis and Clark were produced only during the early years of impoundment (table 24).

Freshwater drum

The regularity of year classes on all Missouri River reservoirs suggests that suitable conditions for good year-class production exist every year. The spawning of drum has not been described in detail, although Davis (1959) found pelagic eggs in Lake Erie. Unpublished studies on Lewis and Clark Lake indicate that drum are not too vulnerable to gill nets, and abundance information on these species is weak.

Yellow perch

Gill net sampling suggests that year-class abundance has been quite regular in Fort Peck, Garrison, and Oahe (table 25). Perch have decreased in abundance

TABLE 24.—*Age distribution, in percent, of river carpsucker taken from Garrison, Oahe, Francis Case, and Lewis and Clark, selected years*

[See headnote to table 17 for references]

Reservoir and year of capture	Number aged	Percent in age group—						
		I	II	III	IV	V	VI	VII+
Garrison:								
1960	16		16	27	37	20		
1961			9	36	45	12		
1962	13	4	6	27	25	24	14	
Oahe:								
1954	271	81	10	3	2	2	3	
1955	142	3	56	11	5	3	6	15
1956	56	37	32	14	7	5	2	2
1959	59	7	46	20	3	9	11	5
Francis Case:								
1954	110	3	84	3	9		2	
1955	222	1	5	88	3	2	(1)	(1)
1956	128	6	10	17	63	2		(1)
1959	70		6	39	24	17	10	(1)
Lewis and Clark:								
1956	205	43	15	13	12	10	6	1
1957	153	2	75	8	7	5	2	1
1958	140		1	63	22	4	6	4
1959	151			6	82	7	3	2
1960	143		1	3	21	68	5	2
1961	139		1	3	6	46	43	1
1962	348		1		6	29	61	3

[1] Less than 1.

TABLE 25.—*Age distribution, in percent, of yellow perch taken from Fort Peck, Garrison, Oahe, and Francis Case, selected years*

[See headnote to table 17 for references]

Reservoir and year of capture	Number aged	Percent in age group—						
		I	II	III	IV	V	VI	VII+
Fort Peck:								
1949	330	(1)	37	25	11	21	6	(1)
1960	38	1	36	62	1			
Garrison:								
1961		2	50	47	1			
1962	14		64	32	3			
Oahe:								
1960	62	71	23	5	1			
1961	159		96	3	1			
1962	195	22	65	12	1			
Francis Case:								
1954	100	49	45	6				
1955	203	2	118	80	1			
1956	164	4	52	39	5			
1959	50		10	70	20			

[1] Less than 1.

in Francis Case and are rare in Lewis and Clark. Conditions are apparently more suitable in the larger reservoirs which more closely approach lake conditions. Higher turbidities characteristic of Lewis and Clark, and to a lesser degree, Francis Case, may limit survival.

Sauger

After the first few years of impoundment, sauger year-class strength appears to have been quite regular in all reservoirs except Lewis and Clark Lake (table 26). This species is vulnerable to gill nets, and the age group distributions presented are probably representative of the populations.

Black crappie

In Oahe and Francis Case, year classes have been produced quite regularly (table 27). Reproduction was erratic in Lewis and Clark Lake.

TABLE 26.—*Age distribution, in percent, of sauger taken from Fort Peck, Garrison, Oahe, Francis Case, and Lewis and Clark, selected years*

[See headnote to table 17 for references]

Reservoir and year of capture	Number aged	Percent in age group—						
		I	II	III	IV	V	VI	VII+
Fort Peck:								
1948	124		5	24	45	15	7	3
1949	134	4	15	23	25	25	8	
Garrison:								
1960	121	1	18	53	15	12	(1)	(1)
1961		19	50	11	12	4		
1962	49	10	49	22	13	7		
Oahe:								
1959	198	22	31	30	13	4		
1960	159	11	16	35	23	13	2	
1961	181	21	54	14	7	3	1	
1962	149	11	48	31	6	3	1	
Francis Case:								
1954	20	95				5		
1955	206	7	91		1		1	
1956	194	6	60	34				
1959	119	10	49	23	16	2	1	
Lewis and Clark:								
1956	25		42	42	16			
1957	64	77	2	11	8	2		
1958	74	18	64	13	2	3		
1959	113	1	7	50	30	12		
1960	109		6	27	62	6		
1961	86	5	12	17	23	36	7	
1962	85	14	31	12	14	14	15	

[1] Less than 1.

TABLE 27.—*Age distribution, in percent, of black crappie taken from Oahe, Francis Case, and Lewis and Clark, selected years*

[See headnote to table 17 for references]

Reservoir and year of capture	Number aged	Percent in age group—					
		I	II	III	IV	V	VI
Oahe:							
1959	52	86	4	2	8		
1960	78	68	10	1			
1961	53	57	30	11	2		
1962	8	37	37	25			
Francis Case:							
1954	159	88	3	4	4		
1955	271	52	47	1		(1)	
1956	176	16	67	14	2	2	
1959	127	28	10	34	23	5	
Lewis and Clark:							
1956	82	61	38	1			
1957	147	98	1	1			
1958	144		100				
1959	156		2	70	27	1	
1960	77		12	17	68	2	1
1961	49		5	63	18	4	
1962	47	2	15	32	21	26	4

[1] Less than 1.

White crappie

Year-class strength in Oahe appeared consistent through 1961 (table 28), but relative abundance appeared to be decreasing in 1962 (table 14). In Francis Case, year-class strength was less consistent than Oahe, and relative abundance was decreasing. Year-class abundance in Lewis and Clark was extremely erratic.

Walleye

Walleye catches, with the gear used, have been too sparse to warrant firm conclusions. Many fry have been planted with little recorded success. No strong walleye year classes have been documented for any Missouri River main stem reservoir. Possibly the fine nature of the bottom materials has hindered survival of eggs. Johnson (1961) studied walleye survival in Lake Winnibigoshish in Minnesota and found that survival on gravel or rubble bottom was 5- to 10-fold greater than on poorly consolidated soils. Many large (7- to 10-pound) walleyes have been caught by anglers, and it is probable that more strong year classes will result after more coarse materials in the reservoir bottom become exposed, as is occurring in Lake Francis Case.

Northern pike

Available data do not allow a reasonable appraisal of northern pike reproduction, but it is known that good year classes were produced in Francis Case in 1958, Oahe in 1959 and 1962, and Fort Peck in 1962. Northern pike require marshy areas for spawning (Franklin and Smith, 1963), but rising water levels do not appear to be essential, since a good 1959 year class was produced in Oahe during receding or stable water level. The Fort Peck 1962 year class was produced during rising water levels. It is noteworthy that no strong year classes of pike were produced in Fort Peck from 1945 to 1953 when the water levels were managed as illustrated in fig. 2 for 1952 and 1953. During this period water levels rose in the spring, to a maximum in late June or early July, decreased generally to an annual low in November or December, and remained low until the spring rise.

Largemouth bass

Moderate year classes of largemouth bass were recorded in Lewis and Clark and Francis Case during the early years of impoundment, but little success has been documented since that time. Since it is

TABLE 28.—*Age distribution, in percent, of white crappie taken from Oahe, Francis Case, and Lewis and Clark, selected years*

[See headnote to table 17 for references]

Reservoir and year of capture	Number aged	Percent in age group—						
		I	II	III	IV	V	VI	VII+
Oahe:								
1959	177	67	25	8				
1960	61	48	46	6				
1961	13	69	31					
Francis Case:								
1954	87	85	9	6				
1955	248	62	36	2				
1956	167	22	73	5				
1959	128	29	17	40	12	2		
Lewis and Clark:								
1956	180	93	6	1				
1957	136	91	8	1				
1958	148	1	98	1				
1959	161	2	13	81	3	1		
1960	139		2	36	55	6	1	
1961	145		1	24	38	34	3	
1962	330	4	5	6	10	22	37	16

known that brood stock is present in all reservoirs, it appears that conditions for reproduction are not regularly suitable.

FORAGE FISH

Martin and Campbell (1953) found that most native stream cyprinids became rare after the Black River in Missouri was impounded into Clearwater Reservoir. Except for the carp and emerald shiner, most cyprinid species are becoming rare in the Missouri River main stem reservoirs (table 29). Although not documented, the emerald shiner is considered to be the most abundant forage species in Garrison Reservoir (Sprague, personal communication), and unpublished data suggest that it is increasing in abundance in Oahe. The silvery minnow, abundant during the early years of impoundment of Oahe, Francis Case, and Lewis and Clark, is decreasing. The emerald shiner, one of the principal forage species in several of the Great Lakes (Flittner, 1964), may fill a similar role in these reservoirs.

The gizzard shad is present in Francis Case and Lewis and Clark, and seining records include only age-group 0 fish. Seining records indicate that it has become less abundant in Francis Case, but it has remained quite stable in Lewis and Clark. In both reservoirs, the adult population is small because of the high mortality of age-group 0 fish during their first winter. Walburg (1964) showed that year classes of adults were produced in Lewis and Clark Lake only when winter ice cover lasted less than 106 days during the first winter of life. This natural control prevents the development of a large adult population unsuitable for forage.

SPORT FISH CATCH

The sport fish catches in Lake Francis Case and its tailwater and in the tailwater of Oahe have been censused in some years. These data show some trends not revealed in net catches.

Lake Francis Case and tailwater

The fishing pressure on the reservoir increased from 1954 to 1960 (table 30). The catch did not change greatly by number

TABLE 29.—*Average number of common forage fish captured per acre by shoreline seining in Oahe, Francis Case, and Lewis and Clark, selected years*

[Data from Fogle (1961a, 1961b, 1963a, 1963b, 1964a, 1964b), Nelson (1961a, 1961b, 1962a, 1962b), Sprague (1958, 1959a, 1959b, 1960), and Shields (1955, 1956, 1957a, 1957b, 1958a, 1958b)]

Reservoir and year of capture	Average number, per acre, of —								Acres seined
	Golden shiner	Silvery minnow	Silverband shiner	Flathead chub	Emerald shiner	Flathead minnow	Red shiner	Gizzard shad [1]	
Oahe:									
1959	----	1,179	(2)	----	----	(2)	----	----	7.0
1960	----	94	136	----	1	5	----	----	7.9
1961	----	127	28	----	6	(2)	----	----	7.0
1962	1	10	----	----	4	(2)	----	----	5.5
Francis Case:									
1956	----	39	----	32	110	(2)	----	157	5.9
1957	----	21	----	3	21	(2)	----	201	5.2
1958	----	11	----	(2)	101	(2)	----	495	5.6
1959	(2)	----	----	(2)	64	----	----	26	4.9
1960	----	158	----	(2)	317	(2)	----	18	4.6
1961	----	7	----	13	117	(2)	----	46	2.6
1962	----	----	1	2	110	----	----	5	3.1
1963	92	----	----	----	1,493	----	----	9	2.6
Lewis and Clark:									
1956	----	405	----	----	7	5	10	29	4.6
1957	----	33	----	1	13	----	14	142	3.0
1958	----	----	----	----	----	----	----	48	2.3
1959	----	----	----	----	205	----	3	310	4.0
1960	----	8	----	5	248	2	7	269	4.5
1961	----	1	----	----	75	----	33	166	2.7
1962	(2)	----	----	1	190	3	8	238	9.3

[1] All age group 0. [2] Less than 1.

of fish caught, but it increased significantly by weight. Important changes in the catch were as follows: (1) Sauger and northern pike became increasingly important; (2) black bullheads were important during early years but almost disappeared by 1960; (3) largemouth bass were decreasing; (4) crappie were becoming abundant; and (5) yellow perch and bluegills decreased in numbers.

The tailwater fishery showed a consistent catch per man-hour from 1954 to 1959 (table 31). Significant changes were as follows: (1) The number of sauger caught remained high, and the average size increased; (2) black bullheads and crappies became rare; (3) paddlefish catch amounted to more than half the weight during the last 2 years of census; (4) walleyes increased. A short-term creel census in the winter of 1959–60 showed a significant decrease in the paddlefish catch (Nelson, 1961b).

Sauger and walleye increased in abundance both in the tailwater and in the reservoir. Crappies were becoming rare in the

TABLE 30.—*Estimated catch of 13 common species and amount of fishing in Lake Francis Case, selected periods, 1954, 1955, 1956, and 1960*

[Data from Shields (1955, 1956, 1957a) and Nelson (1961b)]

Species	May–November 1954		April–December 1955		April–December 1956		May–September 1960	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Sauger	230	55	595	238	1,043	833	28,821	27,956
Northern pike	----------	---------	62	175	157	437	3,407	13,628
Walleye	----------	---------	190	76	177	256	1,386	3,825
Channel catfish	110	205	2,388	955	1,033	1,576	7,610	4,947
Goldeye	40	10	423	140	----------	---------	6,341	3,234
Carp	6,810	4,985	5,234	5,234	----------	---------	1,716	2,574
Black bullhead	32,670	8,455	29,388	7,195	34,202	10,187	751	225
Black and white crappie	----------	---------	3,806	1,256	8,838	2,836	53,934	43,147
Largemouth bass	----------	---------	14,657	11,736	5,116	8,020	2,344	4,688
Yellow perch	25,460	3,880	9,361	1,872	21,039	4,888	3,793	531
Burbot	----------	---------	72	26	----------	---------	----------	----------
Bluegill	35,630	8,615	35,919	6,322	7,174	1,608	277	44
Total catch	114,910	30,990	105,216	35,975	89,421	39,876	114,310	106,180
Catch per man-hour of fishing	1.37	0.37	0.88	0.30	0.56	0.25	0.28	0.25
Man-days of fishing	34,995		40,975		47,485		78,504	
Man-hours of fishing	84,010		119,000		158,849		425,139	

TABLE 31.—*Estimated catch of 14 common species and amount of fishing in tailwater of Lake Francis Case, by periods, May 1954 to March 1959*

[Data from Shields (1955, 1956, 1957a) and Sprague (1958, 1959a)]

Species	May 1954–March 1955		April 1955–March 1956		April 1956–March 1957		April 1957–March 1958		April 1958–March 1959	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Sauger	26,876	33,595	36,351	43,621	14,735	24,077	15,930	27,346	14,215	25,022
Northern pike	----------	---------	52	130	101	459	22	265	138	301
Walleye	484	---------	743	1,115	360	698	91	153	1,323	2,831
Channel catfish	4,964	2,681	13,397	7,234	6,575	13,255	4,453	4,235	6,147	8,043
Goldeye	2,482	---------	5,787	2,315	1,682	685	1,109	364	788	788
Carp	3,027	---------	1,347	1,010	2,229	1,977	4,422	1,587	720	438
Black bullhead	13,317	3,862	5,578	1,617	6,583	2,426	10,492	1,987	167	45
Paddle fish	908	---------	1,674	1,674	124	316	5,518	71,484	4,491	67,365
Black and white crappie	60	---------	41,559	14,540	18,673	5,652	6,122	2,127	2,746	1,039
Large mouth bass	----------	---------	176	132	816	644	----------	---------	568	811
Yellow perch	1,211	---------	8,024	2,006	15,946	2,877	10,514	2,292	3,102	876
Burbot	1,392	---------	2,586	3,879	910	2,083	1,926	3,972	1,136	2,455
Bluegill	1,332	---------	3,660	732	2,134	390	883	135	526	126
Total catch	105,216	---------	126,440	---------	73,803	58,625	66,496	120,230	38,123	112,560
Catch per man-hour of fishing	0.66	---------	0.75	---------	0.68	---------	0.67	----------	0.70	---------
Man-days of fishing	23,700		42,165		27,362		26,353		24,516	
Man-hours of fishing	91,700		----------		108,000		99,000		72,000	

tailwater creel but common in the reservoir catches. Black bullheads and yellow perch decreased in both areas. Channel catfish catches fluctuated within narrow limits. The catch per man-hour did not decrease as much in the tailwater as in the reservoir.

Oahe tailwater

The tailwater fishery below Oahe Dam developed quite differently from that of Lake Francis Case. The Oahe tailwater was upstream from Lake Francis Case, which had been impounded for 6 years, whereas Lake Francis Case was impounded initially above an open river (table 32). In addition, until 1962 the water from Oahe was released through flood tunnels at base level rather than through the turbines. Part of the Oahe tailwater fishery may have been created by fish movement through these tunnels rather than upstream movement from Francis Case. Notable differences were as follows: (1) Catch per man-hour was highest at the start and decreased consistently; (2) large sauger were caught early in the fishery; (3) a northern pike fishery developed at the same time as in Lake Francis Case; and (4) a black bullhead fishery did not develop. As below Lake Francis Case, the crappie fishery was short-lived.

Fogle (1964c) analyzed the catch data in Oahe tailwater and suggested the following: (1) Relatively high and stable releases were conducive to good angling, while large fluctuations depressed the catch rate; (2) angling was best when fishermen could fish within 1,000 yards of the outlet; and (3) northern pike angling was better when the water was released through the outlet tunnels than when water was passed through the turbines.

Fort Peck

In the 1948–50 period the estimated sport catch from Fort Peck increased from 23,630 to 40,700 pounds (U.S. Fish and Wildlife Service, 1952). The predominant fishes caught were yellow perch and goldeye, although burbot and sauger were commonly taken. The tailwater catch during the same period decreased from 22,500 to 6,960 pounds, and consisted principally of sauger and yellow perch.

COMMERCIAL CATCH

Commercial utilization of the fish stocks in these reservoirs has been low. A report

TABLE 32.—*Estimated catch of 12 common species and amount of fishing in tailwater of Oahe Reservoir, by periods, July 1959 to March 1963*

[Data from Fogle (1961a, 1961b, 1963a, 1963b)]

Species	July 1959–March 1960		April 1960–March 1961		April 1961–March 1962		April 1962–March 1963	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Sauger	31,291	65,873	48,544	81,948	57,976	116,682	29,367	42,377
Northern pike	174	978	22,331	84,088	19,498	131,137	4,581	40,718
Walleye	1,869	7,161	2,905	9,419	5,983	7,659	4,968	13,367
Channel catfish	3,596	15,463	7,286	13,801	8,478	15,451	3,250	5,492
Goldeye	8,731	7,770	10,525	8,062	2,434	1,626	2,319	1,668
Carp	1,914	3,780	5,520	1,927	2,867	10,193	1,280	4,961
Black bullhead	390	115	918	275	1,562	561	1,414	560
Paddlefish			3,229	75,153	4,434	113,821	468	10,185
White crappie	38,128	15,983	1,268	818	3,072	721	81	54
Black crappie	(1)	(1)	59	46	1,735	434	146	105
Freshwater drum	11,951	7,360	3,348	2,618	1,295	1,446	661	915
Burbot	1,988	4,047	1,860	5,179	329	1,576	231	956
Others	838	2,753	1,678	13,399	3,190	89,249	962	1,473
Total catch	100,870	131,283	109,461	296,733	112,853	490,556	49,728	122,831
Catch per man-hour of fishing	1.05		0.54		0.45		0.38	
Man-days of fishing	30,033		62,017		57,502		31,423	
Man-hours of fishing	96,467		202,280		248,095		130,484	

[1] Included with white crappie.

from the Bureau of Commercial Fisheries (1962) states that the lack of biological and technological knowledge has prevented development of this industry, and that once the stocks are studied and understood the industry will probably expand. The catch in 1963 amounted to 730,600 pounds (table 33), and the total commercial fishery resource is undoubtedly underexploited. Buffalo made up 90 percent of the catch, but it is known that other species, such as the goldeye, are present in quantity. These other species have not been utilized because of the lack of a market and other technological knowledge.

TABLE 33.—*Commercial catch of fish from Missouri River main stem reservoirs in 1963*

[In thousands of pounds; from Bureau of Commercial Fisheries report]

Species	Fort Peck	Garrison	Oahe	Francis Case	Total
Buffalo [1]	218.4	48.7	23.5	367.6	658.2
Carp	2.4	.5	3.1		6.0
Catfish and bullheads [2]	12.7	2.6		12.0	27.3
River carpsucker	33.4				33.4
Freshwater drum	1.0		3.1		4.1
Suckers [3]	.5			.3	.8
Paddlefish		.8			.8
Total	268.4	52.6	29.7	379.9	730.6

[1] Bigmouth and smallmouth buffalo.
[2] Primarily channel catfish.
[3] Primarily common sucker.

Economic, biological, and social problems in relation to recreational use of the reservoir will also be considered in the expansion of commercial fishing.

DISCUSSION

FISH SPECIES COMPOSITION

As documented by Funk and Campbell (1953) for Clearwater Reservoir in Missouri, by Nokolsky for Russian plains reservoirs (quoted in Poddubnyy and Fortunatov, 1961), by Kimsey (1958) for California reservoirs, and by Chance (1958) for Tennessee Valley Authority reservoirs (quoted in Poddubnyy and number of fish species when a river is impounded into a reservoir. This has occurred on Missouri River reservoirs among the small cyprinids (table 29). Other species that are becoming rare or may have disappeared in some reservoirs are black bullhead, pallid sturgeon, longnose gar, quillback, green sunfish, bluegill, and pumpkinseed.

There are several obvious reasons for fewer fish species in a reservoir than in a natural river. Reservoirs have fewer habitat types than rivers, that is sloughs and various habitats associated with fast current are less common in reservoirs. In addition, lower turbidities in plains reservoirs probably allow predators to reduce the populations of small fish more effectively than in the normally turbid rivers. The young of species that do thrive in reservoirs replace the cyprinids as forage fish. Wadjowicz (1964) reported that species that normally lived in the river produced large year classes during the first year of a reservoir, but became rare after 5 years, when lentic species predominated.

FISH REPRODUCTION

It is noteworthy that most fish species that deposit their eggs on the bottom, or on materials attached to the bottom, have had irregular year-class abundance in these reservoirs. Examples are northern pike, white crappie, black crappie, largemouth bass, sauger, yellow perch, walleye, carp, river carpsucker, smallmouth buffalo, and bigmouth buffalo. Those species that have eggs that are either semibuoyant or limnetic, such as freshwater drum or goldeye, have had quite regular year-class abundance. This relation suggests that environmental conditions that disrupt spawning activity, egg survival, or age-group 0 survival of bottom-spawning species, are strong limiting factors.

Examples of such limiting factors are wind action, bottom type, and fluctuating

water levels. Franklin and Smith (1963) and Kramer and Smith (1960) document the importance of these ecological variables on northern pike and largemouth bass in natural lakes. Pliszka (1953) studied fish populations in a large number of natural lakes in Poland which had northern pike, pike-perch (*Lucioperca lucioperca*), brown trout, coregonids, and a variety of cyprinids. He found that most species could adapt to a wide variety of available foods; only a few coregonids had such restricted feeding requirements that their distribution was limited by food. Many species, however, were restricted from certain lakes by the lack of spawning habitat. Beeton (1965), discussing the eutrophication of Lake Erie, stated that the major factor in the decline of the commercial catch of the more desirable species has been their failure to reproduce.

Reproductive limitations were also considered as paramount in Russian plains reservoirs (Poddubnyy and Fortunatov, 1961). Some solutions to this problem were as follows: (1) For species requiring aquatic plants for egg deposition such as carp, floating mats proved successful; (2) small hatcheries and rearing ponds were deemed necessary on several reservoirs for some species; and (3) suitable water levels were provided when possible. Spawning conditions for many species also were found to be much more suitable before the reservoir reached operating levels.

In the Missouri River reservoirs, it is evident, many of the future problems of fisheries management will be concerned with reproduction and survival of young. It is vital that the ecological conditions that control strong and weak year classes be thoroughly understood. Reproduction limitations are not completely undesirable, because they may give fishery managers control over undesirable species.

FISH GROWTH

Growth rates are controlled by food abundance, fish density, and environmental conditions, such as temperature. Walburg and Nelson (1966), for example, found that growth of carp, river carpsucker, smallmouth buffalo, and bigmouth buffalo in Lewis and Clark Lake was poor as compared with other Missouri River main stem reservoirs and with other areas of the United States. They present evidence which suggests that poor growth was caused by low standing crops of plankton and bottom fauna. Their data did not cover the 1964 period, when abundance of bottom fauna increased greatly over previous years.

There is insufficient data for a discussion of the relations of fish density to growth, but the relation of temperature to plankton abundance warrants some discussion. The annual cycle of plankton abundance in these reservoirs shows near-high numbers under the ice although peak abundance occurs immediately after the ice leaves in April and May (fig. 19, table 8). Under the ice, water temperatures rarely exceed 35° F. (1.7° C.), and it is doubtful whether this plankton food abundance contributes to growth.

Fry (1957) and Brown (1957) reviewed relations between metabolism and growth of fish and stated that low metabolic and growth rates can be expected below 5° C. Molnar and Tolg (1962) reviewed literature on the inverse relation between temperature and gastric digestion rate on carp, burbot, killifish, perch, and pike, and presented original data on pike-perch. Digestion in pike-perch proceeded 8 to 10 times more rapidly at 25° C. than 5° C. They stated that the abundant winter food supply for pike-perch in Lake Balaton was of limited value because of the sluggish digestive activity, even though the stomachs of pike-perch were always full in winter.

Wohlschlag (1960) suggested that, were the mechanisms for regulating metabolism known, it might be possible to artificially raise the metabolic rate of temperate species in winter. Bullock (1955) found some evidence that enzyme activity can be acclimated to low temperature in cold-blooded vertebrates and that adaptation of growth at low temperatures is possible. This problem has many connotations in these reservoirs, but presently we can assume that growth is low during winter.

ENVIRONMENT

Turbidities, wind, and the finely textured soils in the drainage basin appear to be the principal limiting factors in this system for fish production. All are closely interrelated and adversely influence plankton, bottom fauna, fish spawning, egg survival, and feeding activity of fish. Turbidity problems are most severe in shallow areas such as the upper ends and mouths of tributaries of the larger reservoirs, and the entire length of Lewis and Clark Lake. There is some evidence from Lake Francis Case that turbidities may decrease in the future owing to deposition of fine particles in the deeper parts of the reservoirs and exposure of more highly consolidated materials (rocks, rubble) in the shallow areas. The turbidities are caused both by the persistent high winds and by the fine nature of the sedimentary soils. A recent literature review of the effects of suspended soils on fish found no evidence that concentrations less than 25 p.p.m. had harmful effects on fisheries (Food and Agricultural Organization, 1964). It is usually possible to develop good or moderate fisheries in the 25- to 80-p.p.m. range, but good production is unlikely above 80 p.p.m. According to these criteria, Fort Peck, Garrison, and Oahe do not have turbidities that limit fish production significantly.

Because of the size and geological diversity of the drainage area, chemical composition of the water includes all known ions that are considered essential for high biological activity. It is doubtful whether high sulfate concentration in a few tributaries will ever become a limiting factor in the highly buffered main stem waters. Dissolved oxygen deficits may develop more in the future when reservoirs reach operating levels and eutrophication processes accelerate, but high winds may prevent severe deficits.

The extremes in air temperatures in this region are also reflected in water temperatures. In the shallow regions of the larger reservoirs and in Lewis and Clark Lake, high water temperatures can develop quickly during calm periods in the summer. Water temperatures up to 100° F. were recorded in shallow areas of Lake Sharpe in 1964. Winds remove these high-temperature gradients within a short time after their development, but such rapid temperature changes must exert a considerable influence on fish distribution and development of phytoplankton and zooplankton.

FISHERY MANAGEMENT

Fishery management of the Missouri River main stem reservoirs has included (1) introduction of new fish species, (2) stocking of fry and fingerlings of species already present to supplement or replace natural reproduction, (3) liberalization of sport-fishing regulations, (4) contracting of commercial fishing, (5) lowering water levels to discourage carp spawning and (6) raising water levels to promote spawning of northern pike. Several of these practices have been evaluated elsewhere, but some comments are warranted.

The only fish introduction that has proved to be of substantial value is that of the white bass. Few rainbow trout have been caught from the large number of fingerlings introduced, and no substantial fishery has developed. The fate of the ko-

kanee and lake trout introduced in Fort Peck is unknown. There is some evidence that the stocking of northern pike fingerlings in Garrison Reservoir has contributed significantly to some year classes (Sprague, personal communication). It is of interest that Wadjowicz (1964) considered the stocking of pike desirable in a Polish reservoir even though regular reproduction was present.

Control of commercial fishing by contract is a management method that might develop into an effective system for management of reservoir fish populations. The States that administer the contract have control over the amount and kinds of fish removed, type and amount of gear employed, seasons, and location of fishing. Research in progress by the Bureau of Commercial Fisheries will evaluate its use.

The lowering of water levels in Lake Francis Case to reduce carp reproduction (Shields, 1958c) is of questionable value, since carp reproduction has been poor in most reservoirs after the early years of impoundment, regardless of fluctuation patterns.

The raising of water levels in Oahe to benefit northern pike spawning was followed by the strong 1962 year class. However, this rise involved the flooding of new land with its associated terrestrial vegetation. This practice has not been evaluated in an old reservoir where shore vegetation is sparse or absent.

FUTURE PRODUCTION

Some studies in reservoirs have noted a reduction in plankton production within 3 years after new land is flooded, and have also found that many fish species produce phenomenal year classes during the early stages of impoundment of a reservoir. The most striking changes in plankton production have been documented in storage reservoirs with large water level fluctuations (Rodhe, 1962; Ellis, 1937). The production of unusually strong year classes of fish during early years of impoundment has been documented in all types of reservoirs (Kimsey, 1958; Maar, 1960; Walburg, 1964; Wadjowicz, 1964).

The Missouri River main stem system is still in the filling stage, but certain trends have appeared relative to expected plankton productivity. Phytoplankton data have been collected at Williston, Bismarck, and Yankton from 1958 to 1962 and have been summarized by the U.S. Public Health Service (1964). Williston is above the area where new land has been flooded, and there was some evidence of a slight decrease in phytoplankton numbers. Bismarck showed a small increase which could be related to a slight rising water level in Garrison. Yankton showed a significant increase, and this may be related to the flooding of new land at Oahe. It appears that there will be a slight decrease in phytoplankton numbers when the system becomes completely impounded. If, however, turbidities decrease after the finer sediments on reservoir bottoms become concentrated in the deeper areas that are less exposed to wind action, we can expect an increase in plankton productivity.

Alkalinity increased at Yankton and Bismarck, but no trend was observed at Williston. Chemical measurement of conservative ions (those not significantly influenced by biological activity) did not disclose any significant change at any station.

Present knowledge of potential fish production in reservoirs of this type is too fragmentary to predict future fish production. Ryder (1965) found that fish yield of natural lakes at about the same latitude as the Missouri River main stem impoundments could be predicted with reasonable accuracy with a morpho-edaphic index. When this index is applied to these reservoirs, potential fish yield ranges from 2.5 pounds per acre at Fort Peck to 6.3 pounds

per ace in Lewis and Clark. It is probable that these reservoirs, with their continual water renewal, could exceed the above yield figures.

RESEARCH NEEDS

This review has revealed some of the problems concerning fish production in these reservoirs that have already been identified. We now consider the knowledge required to develop these fishery resources to their maximum potential, or at least to a much higher degree of utilization. Exploitation by both sport and commercial fishermen on most of these reservoirs has been relatively light, but resource planners expect much greater use in the future. To effectively utilize the fish populations in these reservoirs, fishery managers must have some knowledge of the following: (1) Actual and potential yield of sport and commercial fishes; (2) influences of water management on fish production; (3) effects of environmental changes by age of reservoir; (4) influences of various degrees and types of exploitation on the fish population; and (5) knowledge of the economics of fisheries.

Hile (1954) described the research problems of the fisheries in the Great Lakes. In predicting the direction of future research, he stated that the standard methods (counting and measuring fish, catch data, stomach analyses, etc.) would not change greatly, but the entire fish population would be considered rather than a few exploited species. In addition, measurements of the environment would be followed more closely in an attempt to explain the changes in fish populations. Briefly, he suggested that a comprehensive approach to the study of a body of water should be used in preference to an intensive study of a few species which include a relatively small part of the total biota.

In these reservoirs, a comprehensive approach must be followed because the environment is subject to greater variation than found in most natural lakes. It is not my purpose to describe how the necessary information is to be collected and analyzed, but only to itemize what data are necessary to derive the principles for effective fisheries management.

Fish population dynamics

Total catch and effort of both sport and commercial fishermen must be followed to evaluate the effects of exploitation. In addition, some type of monitoring of the nonexploited species must be used. Growth, density, mortality, and recruitment of the most abundant species, whether exploited or not, must be known.

Eventually it may be possible to develop practical mathematical or graphical models for prediction purposes. It should be emphasized that environmental conditions will have to be incorporated into these models since it is doubtful whether a "steady environment" will ever develop. Watt (1959) enumerated many problems associated with models in a much more stable environment than these reservoirs, and emphasized the importance of environmental variants.

Life history of fishes

Life history work should be oriented towards determining the causes of changes found in the fish population. Subjects that need special attention are (1) early-life-history studies on the common species with the purpose of determining what conditions control year-class strength, (2) food habit studies as related to available food and in association with other fish species, (3) behavior work concerned with exploitation, feeding, and movements, and (4) factors causing fluctuations in growth and mortality rates.

Environmental parameters

Water temperature controls much biological activity and metabolism. The Corps of Engineers collects continuous water

temperature data from the powerhouses, but additional measurements need to be made in other sections of each reservoir. Dissolved oxygen depletion problems may become more severe when the system reaches operating pool levels, and temperature stratification must be known. The complex chemical nature of this watershed results in significant annual and seasonal changes in ionic content in water. Major ions should be measured on a routine basis. Gross changes can be detected by measurement of conductivity. Water quality stations at Williston, Bismarck, and Yankton provide data on some parameters.

Turbidity is an important and variable condition in this system because of its impact on plankton production and survival of fish eggs and larvae. Persistency and distribution of wind-caused turbidities should be known. Plankton production and its variations have great importance to fish production. Organisms that live on the bottom and on submerged trees should be studied during the aging of these reservoirs; for example, unpublished data on Lewis and Clark Lake show that burrowing mayflies increased three-fold in abundance on flooded farmland after 8 years of impoundment, owing to development of suitable habitat. Other changes will appear in the bottom fauna as fine sediment is removed from shores of these new reservoirs and deposited in deeper areas.

Economics

Many diverse and sometimes conflicting public interests are concerned with the development of water management plans in this reservoir system. Monetary value will be a major consideration for determining which types of development will be established. If the fisheries resource is to receive proper consideration, its economic importance, from both a sport and a commercial standpoint, must be known and understood. Information needed to determine its economic importance includes (1) fish catch and effort expended by both sport and commercial fishermen; (2) expenditures necessary to affect catch; (3) knowledge of the relations of fishing to other uses of the reservoir.

Only after the potential economic value of the reservoir fishery resource is known can we expect to compete successfully with other interests in long-term water management plans.

SUMMARY

The six main stem reservoirs of the Missouri River are part of a large water development plan (Pick-Sloan Plan) which began in 1944 and encompasses the entire Missouri River Basin. These reservoirs have a maximum capacity of 76 million acre-feet and a surface area of 1,261,000 acres. The principal purposes are flood control, navigation, power, and irrigation. Recreational benefits are assigned justification of 0.3 percent of the cost.

The climate and runoff of the basin are subject to great variation. The system can store three times the average annual flow. The impounded land is high plains country and is overlain with vast loosely consolidated sedimentary deposits. High winds are common.

The U.S. Army Corps of Engineers has four operational zones for managing each reservoir: exclusive flood-control reserve; annual flood-control and multiple-use capacity; carryover multiple-use capacity; and inactive capacity. Pertinent data on Fort Peck, Garrison, Oahe, Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake are described.

Shoreline development is least on Lewis and Clark Lake and greatest on Oahe. Average depth varies from 15 feet in Lewis and Clark to 79 feet in Fort Peck. Garrison Reservoir floods the flattest terrain, and average depth changes little at different water levels within the operating pool.

Fort Peck, Garrison, and Oahe stratify thermally, but high winds usually disrupt stratification in Francis Case and Garrison. Surface temperatures average about 10° F. lower at Fort Peck than at Lewis and Clark. All reservoirs develop surface temperatures above 75° F. in late July and August. These reservoirs froze for periods ranging from 85 to 123 days, from 1958 to 1964. The spring warmup process begins in the upper end of each reservoir and advances toward the dam and to greater depths as the season progresses. Thermoclines are extended.

Density currents were found only in the upper end of Fort Peck for short periods in late spring and early summer.

Turbidities have been drastically reduced with the impoundments. Temporary turbidities caused by wind and incoming streams are serious problems in Lewis and Clark Lake and in the upper ends and major arms of all reservoirs. Flat clay particles, which are low in weight but effectively shield out light, cause the turbidity. Limit of visibility, as measured by a Secchi disk, averaged less than 2 feet in Lewis and Clark Lake but reached 13 feet in Garrison near the dam.

Total dissolved solids ranged from 205 to 627 p.p.m. Bicarbonates, sulfates, calcium, sodium, and magnesium are the most common constituents. Differences in total dissolved solids by season and location in Fort Peck and Garrison were plotted. Reservoir regulation delayed normal trends in alkalinity. Photosynthetic activity removes some alkalinity from solution by marl deposition.

Dissolved oxygen concentrations normally varied from 80 to 120 percent saturation, although some lower readings were made in Oahe and Lake Francis Case. It does not appear that any of the known essential ions for biological production are lacking or in excess in this system. Phytoplankton studies are reviewed. Maximum numbers were found in May and June, and minimums in July, (and average numbers during other periods). Plankton counts were higher below Lewis and Clark than below Garrison or Fort Peck.

Bottom fauna data are weak, but there is evidence that Lewis and Clark Lake developed suitable conditions for *Hexagenia* after 8 years of impoundment.

Fish population data were collected from some reservoirs by gill nets, frame nets, and seines. Interpretation of collecting methods is discussed. There have been 59 species collected in these reservoirs. Introductions are white bass, rainbow trout, kokanee, and lake trout. A species list is presented for each reservoir. Fort Peck has some mountain stream fishes; differences in species composition are not great among the other reservoirs. Gizzard shad are present only in Francis Case and Lewis and Clark. Northern pike, goldeye, and yellow perch were more abundant in Fort Peck, Garrison, and Oahe than in the lower reservoirs.

Distributions of some species in summer by depth and area of reservoir are discussed. Relative abundance of northern pike, sauger, crappie, yellow perch, goldeye, carp, and river carpsucker are compared among reservoirs from gill net catches. Growth rates of sauger, carp, river carpsucker, freshwater drum, and goldeye are compared among reservoirs.

Year-class strength, as determined by abundance of adult fish, was compared among reservoirs for carp, river carpsucker, goldeye, freshwater drum, yellow perch, sauger, black crappie, white crappie, walleye, northern pike, and largemouth bass. In general, species that deposit their eggs on the bottom or on materials attached to the bottom had irregular year classes. Goldeye and freshwater drum, which have semibuoyant eggs, had quite regular reproduction.

Of the forage fishes, the emerald shiner

appears to be increasing in abundance. The gizzard shad is abundant in Francis Case and Lewis and Clark.

Sport fish catch data from Lake Francis Case and its tailwater and from the Oahe tailwater are summarized. Sauger and northern pike were increasing in importance in Lake Francis Case. A paddlefish fishery in the tailwater of Francis Case was temporary. The commercial catch from this system in 1963 was 730,600 pounds, and buffalo made up 90 percent of the catch.

Present fishery management and research needs to manage the fish population are discussed.

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APPENDIX

APPENDIX TABLE 1.—*Average catch of five common species per 250-foot gill net set in Fort Peck Reservoir, 1949 and 1953*

[In number of fish; data from Phenicie (1950) and Alvord (1953)]

Species	1949 (27 sets)	1953 (9 sets)
Goldeye	41.0	42.0
Yellow perch	43.3	10.9
Sauger	4.2	4.2
White sucker	2.6	.8
Carp	.6	3.0
Catch per set	94.3	64.5

APPENDIX TABLE 2.—*Average catch of 14 common species per 250-foot gill net set in Garrison Reservoir 1959 to 1961*

[Data from Van Wyhe (1960) and Sprague (1961a, 1961b, 1963)]

Species	1959 (50 sets)		1960 (78 sets)		1961 (66 sets)		1962 (78 sets)	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Goldeye	36.5	18.2	29.5	14.7	41.7	20.8	31.2	13.6
River carpsucker	.2	----	.4	.6	.5	1.1	1.4	3.3
Buffalo	1.0	2.0	.4	.9	.7	3.3	.4	1.5
White sucker	4.8	4.8	4.4	4.3	3.4	3.4	2.2	2.4
Channel catfish	.6	1.7	1.0	1.8	.7	1.6	.8	1.8
Black bullhead	3.1	7.7	3.0	.7	2.2	.4	6.7	1.7
Burbot	.1	.1	.1	.1	.1	.2	.1	.1
Northern pike	.2	1.3	.3	1.8	.9	1.9	.9	2.5
Sauger	4.2	4.4	5.7	5.7	5.0	5.0	4.6	4.3
Walleye	.6	1.6	.5	1.9	1.3	1.5	1.9	2.0
Freshwater drum	.6	.6	1.2	1.2	1.4	1.4	2.1	1.4
Crappie	3.6	.6	4.0	1.3	7.1	1.8	6.2	1.5
Yellow perch	7.7	1.9	7.0	1.7	8.1	1.5	4.0	.5
Carp	7.3	8.4	5.5	8.2	7.4	12.0	8.7	17.5
Catch per set	71.4	47.6	62.9	46.0	80.6	56.3	71.2	54.7

APPENDIX TABLE 3.—*Average catch of 16 common species per 250-foot gill net set and per frame net set in Oahe Reservoir, 1959 to 1962*

[Data from Fogle (1961a, 1961b, 1963a, 1963b)]

Species	1959			1960			1961			1962		
	Frame nets (107 sets), number of fish	Gill nets (103 sets)		Frame nets (105 sets), number of fish	Gill nets (101 sets)		Frame nets (99 sets), number of fish	Gill nets (99 sets)		Frame nets (71 sets), number of fish	Gill nets (71 sets)	
		Number	Pounds		Number	Pounds		Number	Pounds		Number	Pounds
Northern pike	1.7	0.8	0.6	1.2	7.0	11.2	0.3	2.4	9.7	1.3	0.7	2.8
Goldeye	.3	11.7	11.7	----	1.0	.5	----	4.4	2.9	----	2.5	2.2
Carp	235.9	45.6	16.8	44.9	15.9	6.9	6.8	10.9	10.9	6.3	3.5	5.0
Bigmouth buffalo	1.4	1.0	.2	1.4	5.7	1.9	.8	1.9	2.1	2.5	.1	.2
Smallmouth buffalo	.6	.2	.5	.3	3.1	.6	.4	1.3	1.0	----	.1	.1
River carpsucker	4.4	1.2	1.5	.5	1.0	.7	.4	1.1	1.3	2.3	.6	.7
Shovelnose sturgeon	----	4.3	4.5	----	5.6	3.3	----	3.4	2.8	----	5.8	4.5
Channel catfish	1.2	1.2	1.5	.2	.2	.2	.1	.8	.1	1.4	1.3	.3
Black bullhead	2.5	.5	.1	.2	.3	.1	----	.2	.1	----	.1	----
White crappie	3.1	.1	----	.2	.4	.1	.2	.4	.1	----	----	----
Black crappie	1.2	----	----	.9	.2	.1	.6	.1	.1	.1	----	----
Yellow perch	----	----	----	.3	.5	.1	2.2	4.3	.5	3.1	5.0	.6
Sauger	2.1	3.8	7.0	.4	1.3	1.4	.2	4.2	3.2	.1	3.1	2.4
Walleye	----	----	----	----	.1	.1	----	.2	.2	----	.3	.2
Freshwater drum	.4	.1	.1	.1	.3	.1	.3	.9	.1	----	.1	.2
Shortnose gar	1.6	.3	.3	.6	.2	.1	.1	.1	.1	.1	----	----
Catch per set	225.9	71.1	45.2	51.3	43.5	27.54	11.6	34.0	35.7	11.2	22.7	21.2

APPENDIX TABLE 4.—*Average catch of 15 common species per 250-foot gill net set and per frame net set in Lake Francis Case, 1954, 1955, 1956, and 1959*

[Data from Shields (1955, 1956, 1957a) and Sprague (1959a)]

Species	1954, Frame nets (18 sets)		1955				1956				1959			
			Frame nets (90 sets)		Gill nets (90 sets)		Frame nets (52 sets)		Gill nets (37 sets)		Frame nets (35 sets)		Gill nets (35 sets)	
	Number[1]	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Shortnose gar	5	4.7	1.6	2.4	0.6	0.9	0.1	0.3	0.1	1.6	0.2	0.1	0.1	0.2
Goldeye					2.9	1.2			7.9	4.0	.1	(2)	4.3	3.1
Carp	67	32.3	14.5	14.5	16.6	16.6	6.2	11.1	10.8	15.7	1.7	2.5	5.9	11.3
River carpsucker	5	1.7	2.5	1.7	3.9	2.6	.5	.9	4.3	6.7	.6	.8	3.4	6.0
Bigmouth buffalo	4	2.6	2.9	4.6	4.3	6.8	.3	.9	.8	2.6	.1	.3	.2	1.4
Smallmouth buffalo	2	.4	2.3	2.2	2.7	2.6	.1	.1	1.0	2.0	.1	.2	1.6	.7
Channel catfish	1	.8	.3	.2	2.7	1.8	.1	.1	4.4	3.8	.1	.1	3.7	3.1
Black bullhead	20	5.1	6.9	2.0	11.2	3.3	1.2	.5	4.7	2.0				
White crappie	4	.6	5.6	1.0	4.5	.8	6.2	1.9	4.9	1.3	4.5	1.0	2.9	1.1
Black crappie	14	1.8	45.3	8.7	1.3	.3	81.5	31.2	2.1	.6	10.2	3.9	.3	.4
Sauger			.3	.3	3.8	3.4	.3	.6	6.9	11.1	.4	.5	5.5	8.6
Yellow perch	2	.3	2.6	.5	3.5	.7	5.9	1.6	7.2	1.8	.3	.1	1.1	.3
Bluegill	4	.6	19.3	3.0	.2	.3	10.4	2.9			.3	.1		
Northernpike			(2)	.1	.1	.3	.1	.5	(2)	.1	.2	1.1	.3	1.7
Freshwater drum	5		2.4		6.3		.2		4.5		0.8		1.2	
Catch per set	134	51.9	107.7	41.5	82.1	48.9	114.1	53.3	64.9	57.9	20.8	11.8	29.9	38.7

[1] Numbers available to whole numbers only.
[2] Less than 0.1.

APPENDIX TABLE 5.—*Average catch of 11 common species per 250-foot gill net set and per frame net set in Lewis and Clark Lake, 1956 to 1962*

[Data from Shields (1957b, 1958a), Sprague (1959b, 1960), Nelson (1961a, 1962b), and Walburg (1964)]

Species	1956				1957				1958				1959			
	Gill nets (32 sets)		Frame nets (51 sets)		Gill nets (39 sets)		Frame nets (44 sets)		Gill nets (51 sets)		Frame nets (50 sets)		Gill nets (54 sets)		Frame nets (48 sets)	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Shovelnose sturgeon	10.4	7.1	----------	----------	10.1	6.5	----------	----------	0.1	0.7	----------	----------	2.3	1.5	----------	----------
Shortnose gar	.9	1.0	0.1	2.7	1.2	1.3	2.8	3.9	.8	.4	2.7	3.0	.7	1.1	2.4	2.3
Bigmouth buffalo	1.5	.4	.5	.4	1.4	.3	.6	.5	1.5	1.4	.3	.4	1.3	1.8	.5	.7
Smallmouth buffalo	.2	1.0	.1	----------	.7	.8	2.4	.3	1.9	.8	1.3	----------	1.8	1.7	.6	.5
River carpsucker	1.8	2.5	16.3	4.6	5.7	1.5	15.0	4.3	8.3	3.9	8.7	3.5	7.1	3.7	5.2	2.0
Carp	21.1	6.4	125.7	31.5	29.1	7.0	79.0	23.0	20.8	7.9	14.1	5.6	20.9	9.0	6.9	3.1
Channel catfish	8.6	5.7	3.6	1.9	6.8	4.7	.4	.3	4.0	3.0	.3	.2	3.9	3.4	.1	.1
White crappie	.5	.1	4.4	.6	2.0	.2	10.0	.9	9.9	1.2	46.4	4.5	2.6	.4	33.0	3.5
Black crappie	----------	----------	2.8	.4	1.8	.1	105.1	7.2	.2	.2	50.9	6.1	.1	----------	18.6	1.9
Freshwater drum	.4	.2	.9	.3	.9	.1	.3	.1	.6	.1	.5	.1	.5	.1	.2	.5
Sauger	.6	----------	.1	----------	1.3	----------	.4	----------	1.0	----------	1.0	----------	2.1	----------	.8	----------
Catch per set	50.6	29.8	159.7	43.1	70.8	32.6	220.5	41.9	53.5	24.1	131.7	26.3	45.9	29.4	71.9	16.5

Species	1960				1961				1962			
	Gill nets (33 sets)		Frame nets (30 sets)		Gill nets (36 sets)		Frame nets (33 sets)		Gill nets (27 sets)		Frame nets (56 sets)	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Shovelnose sturgeon	0.5	0.5	----------	----------	1.6	1.03	----------	----------	3.1	----------	----------	----------
Shortnose gar	1.2	1.8	3.3	3.8	3.8	1.6	3.8	4.5	.9	----------	0.6	----------
Bigmouth buffalo	.5	1.2	.1	.4	.9	2.4	.1	.2	.2	----------	.2	----------
Smallmouth buffalo	2.5	1.6	.4	.3	1.2	.9	.5	.5	1.0	----------	1.1	----------
River carpsucker	10.2	5.3	3.5	2.3	10.4	5.2	5.0	3.2	5.1	----------	9.8	----------
Carp	18.4	7.3	3.7	3.1	17.4	7.9	7.3	5.5	16.7	----------	9.0	----------
Channel catfish	4.5	3.6	.1	.2	5.4	5.4	----------	----------	7.6	----------	.1	----------
White crappie	2.5	.4	4.9	1.2	1.7	.3	17.6	3.9	1.6	----------	6.3	----------
Black crappie	----------	----------	2.9	.5	.1	----------	1.8	.3	.1	----------	.9	----------
Freshwater drum	.8	.2	.2	.1	1.1	.3	.3	.1	6.0	----------	1.2	----------
Sauger	3.0	----------	.4	----------	1.8	----------	.8	----------	1.9	----------	.7	----------
Catch per set	46.4	29.7	22.7	14.1	45.6	31.9	40.1	21.6	65.6	----------	38.5	----------

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UNITED STATES
DEPARTMENT OF THE INTERIOR
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